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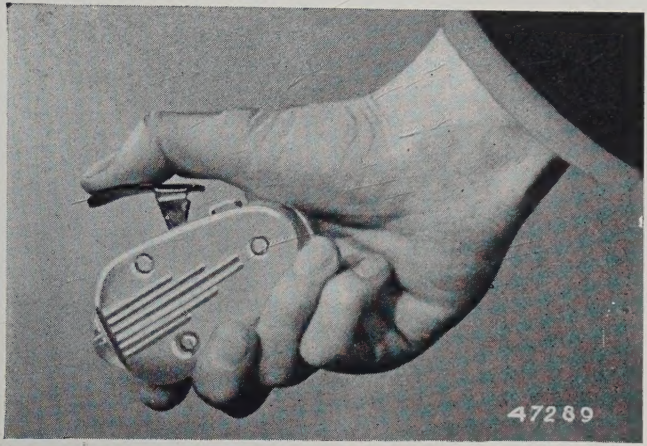


THE DYNAMO POCKET TORCH

by E. A. van IJZEREN. **621.313.39-871**

Description of the Philips dynamo pocket torch type No. 7424. When squeezed "normally" it generates a light flux of 2·4 lumens, for which the user has to apply about 0·9 watt of mechanical energy. In spite of the intermittent excitation the light flux varies only little while the dynamo is being squeezed. This is due partly to a large moment of inertia and high speed of rotation of the rotor and partly to the flatness of the voltage — speed characteristic. The dynamo, which on broad lines is analogous to a bicycle dynamo, contains a permanent magnet of eight poles made of "Ticonal" 0.8 as rotor. The armature winding is on a stator of a construction very different from that commonly used and adapted to a high degree to mass production. The dynamo is made resistant to short-circuiting, as will be explained.

In this mechanized age it is not often that man reverts to the use of his own physical strength to perform work which he has long been accustomed to have performed by other sources of energy. That is, however, what has occurred on a miniature scale in recent years since the dynamo pocket torch came to occupy an important position side by side with the traditional battery pocket torch. This development was stimulated by the fact that during the war batteries became scarce, while black-out precautions increased the need of a pocket torch. But now that war scarcity and blackout are things of the past the dynamo pocket torch still appears to be in great demand, obviously because the public has become more conscious of the disadvantages of the battery torch even in peace time: the necessity of repeatedly buying new batteries and the chance that at a critical moment the batteries kept on hand will be found to be exhausted when the torch has not been used for some time. These disadvantages are especially pronounced in tropical countries, where batteries deteriorate more quickly and fresh supplies have sometimes to be fetched a long distance away.

There is another example where light is generated by physical strength; the bicycle lamp. In the development of the dynamo pocket torch extensive use has been made of the experience gained in the construction of modern bicycle dynamos. This will become evident in the following description of the Philips dynamo pocket torch, type no. 7424 [1])

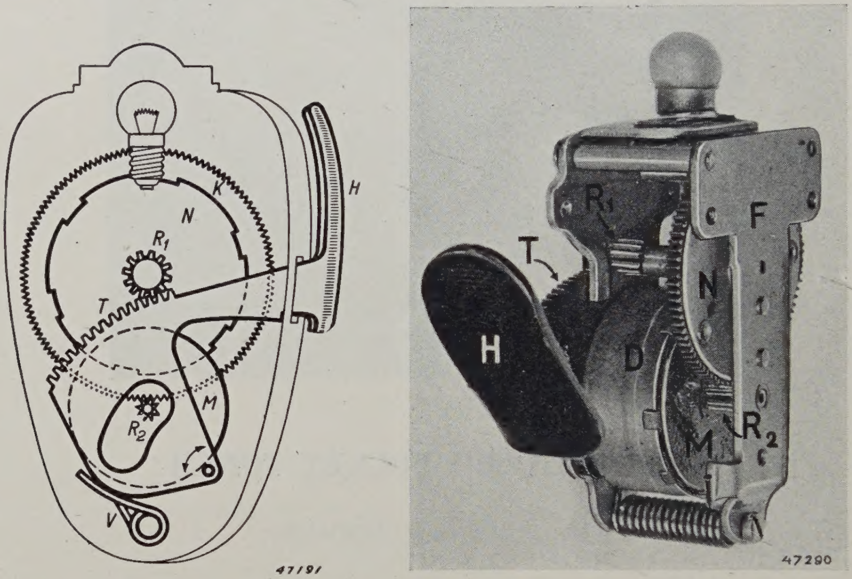
General construction

The construction of the dynamo itself is very similar to that of a bicycle dynamo. The magnetic field is produced by a permanent magnet in the form of a rotor, while the armature winding, in which an alternating e.m.f. is generated by the rotation of the magnet, is on a soft iron stator. With this principle of construction, which has become a practical possibility since magnet steels of very high magnetic power have become available, the collector with brushes and the separate excitation of the field found in ordinary dynamos are dispensed with, and these simplifications alone have made it possible to produce dynamos sufficiently small and reliable for the purpose.

The small lamp fed by the dynamo is mounted on the dynamo itself and the light emitted is concentrated by a small lens and reflector.

Since the rotor of the dynamo has to be driven by the same hand that holds the torch and directs its light, rotary drive is out of the question. A squeezing motion, either with the palm or with the thumb, is practically the only motion that can be reconciled with the other two functions of the hand.

In our case thumb pressure has been chosen. The mechanism of the motive power based on this principle is shown diagrammatically in *fig. 1a*. The lever, which is pressed in periodically against the action of a spring, is attached to a gear rack which sets the rotor of the dynamo in motion *via* a pinion and cogwheel transmission with freewheel. Thanks to the freewheel the rotor continues to move without hindrance when the lever springs back. The rotor, driving cogwheel and lever spindle bearings are in a frame entirely enclosed in the casing. Lubrication is provided by a small piece of cloth drenched with oil and clamped to the bearings. The photograph in *fig. 1b* shows how all the components are assembled in the frame (with the casing removed).



a *b*

Fig. 1. *a*) Mechanism of the rotor in the Philips dynamo pocket torch type no. 7424. The lever H with the rack T is pressed in periodically with the thumb against the force of the spring V. *Via* the pinion R_1, T drives the freewheel N. When the lever is pushed in N carries with it the toothed rim K, which, *via* the pinion R_2, drives the rotor M, while upon the lever H being allowed to spring back the toothed rim and the rotor continue to turn freely. *b*) The dynamo pocket torch with casing removed. F frame, H lever with rack T, R_1 pinion, N cog wheel transmission with freewheel, R_2 pinion on the spindle of the rotor M, D dynamo.

With "normal" squeezing the dynamo yields an average effective voltage of 2.5 volts and supplies the lamp with a power of about 0.3 watt. Losses due to friction, eddy currents, etc, make it necessary for the user to apply a mechanical energy of 0.9 watt.

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[1] In addition to the type described, a second, smaller dynamo pocket torch (the "Byou", type no. 7426) has also been developed by Philips. We shall, however, confine ourselves here to the first-mentioned type.

Since the lamp will usually only be in continuous use for relatively short times, a total lifetime of 10 hours is considered sufficient. The lamp therefore burns as it were on "overvoltage" for the sake of better light efficiency. The light flux obtained (always with "normal" squeezing) amounts to 2.4 lumens, half of which is irradiated from the lamp as effective light. In the beam proper at a distance of 1 m an illumination intensity of about 4 lux is obtained.

The overall dimensions of the torch are 8.5 × 5 × 3 cm, with a total weight of only 215 grams, so that it can very well be carried in the coat or trousers pocket or in a lady's handbag.

Mechanical details of the construction

A bicycle dynamo gives off about 3 watts electrical power and requires about 9 watts mechanical energy from the cyclist. The power of the pocket torch dynamo is therefore about 1/10 of that of a bicycle dynamo. This ratio is not unreasonable, considering the volumes of the muscles concerned in each case in the production of the mechanical energy and taking into account that the leg muscles have to drive not only the dynamo but also the bicycle 2). A more direct method of obtaining some idea of the mechanical energy which can be demanded of the thumb is to calculate the squeezing power. In squeezing, the thumb can only make a stroke of a few centimeters and cannot repeat the squeezing motion more than a few times per second. If s is the stroke in cm and n the number of strokes per minute, the squeezing power P which the thumb must exert upon pressing in the lever in order to produce an average power of N watts is

$$P = 612 \, \frac{N}{s \cdot n} \text{ kg.}$$

In the case of the dynamo pocket torch described here the stroke at the extremity of the lever where the thumb acts is about 3 cm. From tests with different persons it has been found that a frequency of about 180 strokes per minute may be considered as normal. The force of the squeeze required for $N = 0.9$ W is then about 1 kg. Added to this is the force of about 0.5 kg necessary to overcome the pressure of the spring tending to push the lever back. With a total force of 1.5 kg one is clearly not far from the limit of what can be demanded of the thumb muscles: a much greater force of squeeze would in most cases lead too quickly to fatigue.

The transmission ratio of the cogwheels is so chosen that, at the normal frequency mentioned and with a ratio of about 1 : 1 between the times for pressing down the lever and its return, the rotor attains a speed of about 4000 r.p.m. Such a high speed is desired for the dynamo to function in a sufficiently flat part of its voltage—speed characteristic, a requirement which will be discussed later. Moreover, a high number of revolutions makes it possible to accumulate rotation energy in the rotor with a relatively low moment of inertia, thus small dimensions and light weight, so that in spite of the periodic interruption of the motive power the rotor continues to run with sufficient uniformity. Much higher speeds than the one mentioned can hardly be considered, because a second cogwheel transmission would then be required, which would reduce too much the mechanical efficiency and cause the noise of the mechanism to assume undesirable proportions. In order to minimize the noise as far as possible, the toothed rim on the freewheel is made of the well-known "hard tissue" frequently used for damping the sound of gearwheels, which consists of compressed layers of fabric impregnated with artificial resin ("Philitext").

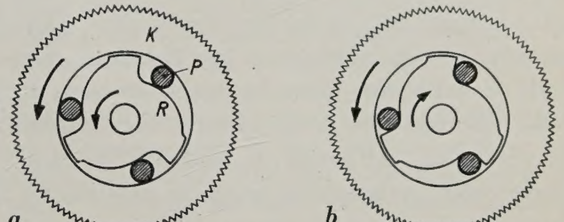

Fig. 2. Construction of the freewheel. Upon the hub being rotated in one direction the three rollers P roll along the face R of the three teeth upwards (a), become jammed between R and the toothed rim K and thus carry the latter along. When the hub is rotated in the opposite direction the rollers run down again (b) and no longer make contact with the rim K, which can thus continue to turn freely in the direction in which it started.

The construction of the freewheel (*fig. 2*), which periodically carries the toothed rim along with it and then allows it to run on freely, is also designed to produce little sound and, moreover, as little friction as possible during the freewheeling.

The desired moment of inertia of the rotor can be obtained by affixing a lead disc on the rotor spindle beside the permanent magnet. The whole must be well balanced in order to ensure smooth running of the rotor, without vibrations.

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2) With an ordinary bicycle and moderately good tyres a power of, for instance, 30 to 100 watts, according to the condition of the road surface, in very unfavourable conditions even up to 200 watts, is necessary for a speed of 15 km/hr.

Electrical and magnetic details

The voltage—speed characteristic

At low speeds the terminal voltage of an A.C. dynamo under a certain permanent load resistance is proportional to the number of revolutions, but at higher speeds it becomes more and more independent of the number of revolutions.

This phenomenon and the measures which have to be taken to obtain the flattest possible voltage—speed characteristic have already been discussed in this periodical in connection with the description of a bicycle dynamo [3]). Since the same considerations apply to the pocket torch dynamo we shall go into them in somewhat more detail.

To begin with it must be explained in how far a flat characteristic is of importance for the torch dynamo. Though a cyclist usually rides at a fairly constant speed, this will sometimes be high (for instance 25 km/hr) and sometimes lower, while there are also cases where he dismounts and wheels the bicycle along a short distance (5 km/hr). A flat characteristic is therefore necessary for a bicycle dynamo in order on the one hand to obtain sufficient light from the lamp at 5 km/hr and on the other hand not to overload the lamp at 25 km/hr. In the case of the dynamo pocket torch the situation is somewhat different, for the average speed of squeezing will vary only slightly at different times, certainly not more than by a factor 2, compared with a factor 5 in the case of the bicycle dynamo. Thus for the same voltage variation a less flat characteristic would be sufficient. Here, however, we have a new factor: the variation in the speed of the rotor during the squeezing. Although an attempt is made to reduce these variations as much as possible by the above-mentioned enlargement of the moment of inertia, it is clear that a limit is set by the fact that the torch has to be kept small and light. The fluctuations in speed which may still remain are shown in *fig. 3* for a certain, rather unfavourable case. If it is desired to prevent these speed variations from causing a disturbing fluctuation of the light flux, the solution must again be sought in making the voltage—speed characteristic as flat as possible, especially because of the very small heat inertia of the filament, which is only 12 μ thick.

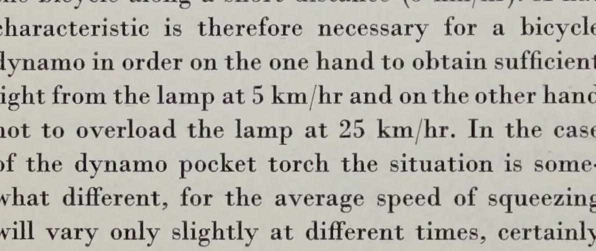

Fig. 3. Variations in the number of revolutions of the rotor caused by the intermittent drive, upon periodic squeezing in this case about 120 strokes per minute and a ratio of about 1 : 2 between the times of pressing in and the releasing of the thumb.

The terminal voltage becomes independent of the number of revolutions when the inductive resistance of the armature winding, which is proportional to the frequency of the A.C. voltage excited and thus to the speed of revolution, is large compared with the ohmic resistance of the armature winding plus lamp. Since the inductive resistance increases according as a higher flux is excited in the armature by a given current, it is desirable to keep the magnetic resistance of the armature circuit low. Furthermore, it is desirable to have a large number of poles on magnet and stator, since at a low speed the voltage generated still has a high frequency.

The magnet of the pocket torch dynamo has eight poles, so that at 4000 r.p.m. the frequency of the A.C. voltage generated amounts to about 250 c/sec. For a compact construction it is important that no actual projections need to correspond to these poles: the magnet (like that of a bicycle dynamo) consists of a short smooth cylinder, magnetized in eight poles along the periphery. Such a construction was very uneconomical with the magnet steels formerly available, for, as soon as the magnet is transferred from the magnetizing apparatus to the ultimate circuit, the flux produced by two neighbouring magnet poles then has a certain tendency to close inside the cylindrical shell through the steel, instead of acting outwards. In order to prevent this it is necessary that the magnet steel lying between the poles along the circumference of the cylinder should offer a high resistance to the reversal of the direction of magnetization thereby occurring. The magnet steel "Ticonal" 0.8 used for the pocket torch dynamo possesses this property to a high degree [4]).

Accompanying the property mentioned there is generally a low reversible permeability, *i.e.* the magnetization is little affected by small fluctuations of the magnetizing field. In particular, therefore, the armature reaction has little effect on the magnet, which promotes the stability of the whole. On the other hand, if we desire to obtain a flat voltage-speed characteristic, a low reversible permeability is an obstacle to the second requirement that the current through the armature winding must excite a strong counter flux. In as far as it has to pass through the magnet this field then experiences a fairly high magnetic resistance. The counter-field is therefore given the opportunity of completing itself for a large part outside the magnet, *i.e.* the magnetic circuit of the armature winding is made with a wide spread.

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[3]) H. A. G. Hazeu and M. Kiek, An alternating current dynamo with a flat characteristic for bicycle lighting, Philips Techn. Rev. **3**, 87, 1938.

[4]) As a closer consideration will show, the condition can be formulated more precisely as follows: the demagnetization curve, especially near the turning point of the magnetization, must have a small slope. For this purpose it is desirable that the steel, compared to the residuum, should have a large coercive force — a property which the older magnetic steels (tungsten steel) possessed to a much smaller degree; *cf*. the full-drawn and the dotted magnetization curves in fig. 6.

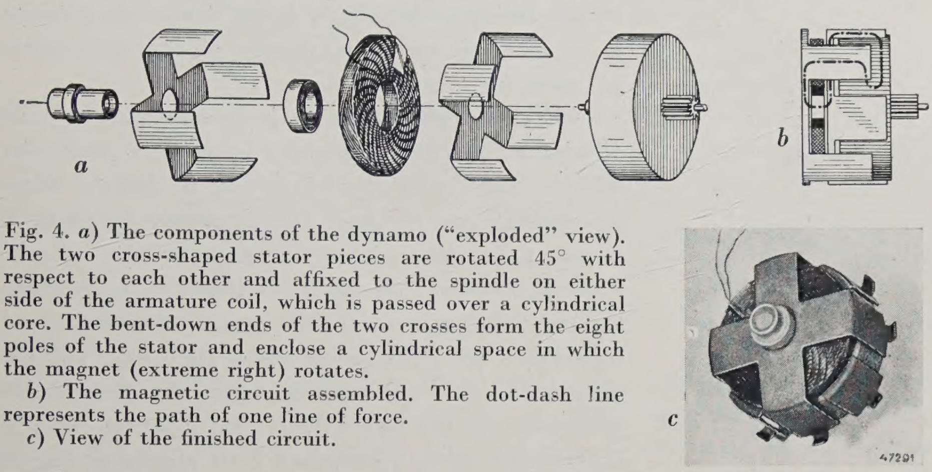

Fig. 4. *a*) The components of the dynamo ("exploded" view). The two cross-shaped stator pieces are rotated 45° with respect to each other and affixed to the spindle on either side of the armature coil, which is passed over a cylindrical core. The bent-down ends of the two crosses form the eight poles of the stator and enclose a cylindrical space in which the magnet (extreme right) rotates.
b) The magnetic circuit assembled. The dot-dash line represents the path of one line of force.
c) View of the finished circuit.

The form of the magnetic circuit, which deviates very much from the usual form, may be seen in *fig. 4.* It is formed by two cross-shaped pieces of soft iron sheet with the ends of the arms bent over at an angle of 90°, and a cylindrical soft iron core over which the armature winding is placed. The two crosses are fastened against the ends of the cylindrical core. The inner cross has slightly shorter arms than the outer one. Due to the fact that the two crosses are rotated 45° with respect to each other, the four bent ends of one cross fall between those of the other, and the eight ends, which function as stator poles, together enclose a cylindrical space in which the magnet rotates. Armature coil and magnet in this peculiar circuit are thus arranged as co-axial cylindrical discs. In fig. 6*b* the course of the lines of force can be followed with the help of the example given; fig. 6*c* is a photograph of the circuit fully assembled.

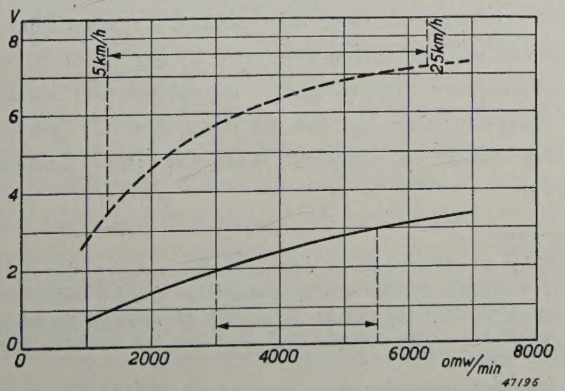

Fig. 5. Relation between the terminals voltage and the number of revolutions of the pocket torch dynamo with permanently connected lamp for 2·5 V, 0·1 A. The dotted line represents the corresponding relation for the Philips bicycle dynamo type no. 7722 equipped with a lamp for 6 V, 0·5 A.

It is clear that this circuit will have the desired large spread, considering the great length over which it travels between neighbouring stator poles adjacent to each other at such relatively short intervals.

In *fig. 5* the voltage—speed characteristic is reproduced, which is obtained with the construction described. Thanks to its flatness, in spite of the fluctuations in the speed during the periodic squeezing only a slight flicker occurs in the light of the lamp, which is scarcely perceptible.

Owing to its peculiar construction the magnetic circuit is specially adapted to the requirements of mass production. An important point, for example, is that the armature winding can be prepared in advance on a winding machine in the form of a simple disc-like coil, to be passed over the core before the two cross-shaped pole plates are put on.

The fact that the magnet is constructed as a smooth cylinder without projecting poles is also very important for mass production. The magnet steel, cast in the desired shape and hardened, is so hard and brittle as to allow of practically no other processing than grinding. The prescribed simple cylindrical shape makes it possible for the grinding to the precise dimensions of the magnet to be carried out by a method particularly suitable for mass production, namely on a so-called centerless grinding machine, which process costs relatively little in time and energy.

Safety measures against short-circuiting.

Due to the wide spread of the magnetic circuit, the necessity of which was explained above, magnetic energy is "spilt". Thanks to the high output of magnetic energy per unit of volume of the magnet steel "Ticonal" 0.8 this extravagance is permissible, without it being necessary to have recourse to too heavy a magnet, in order to excite the necessary flux in the armature. It is even possible to go farther and to sacrifice still more of the magnetic energy to make the dynamo insensitive to short-circuiting, as will be seen from the following.

Fig. 6 gives the demagnetization curve of the magnet steel, *i.e.* that part of the magnetization curve which gives the induction (in gauss) as a function of a demagnetizing field (in oersted). Given the magnetic resistance of the circuit, the relation between the induction and the field is represented by a straight line through the origin, for instance k in fig. 6. At the point of intersection A of this line with the curve the induction may be read off which the steel will retain when, after magnetization to saturation, it is placed in the circuit in question. When, due to the rotation of the magnet, a current begins to flow in the armature winding, it will excite a counter-field, which causes the induction to fall from A to B; upon the current falling to zero the induction increases again, not along the magnetization curve but along the practically straight line BC, the slope of which is equal to the previously mentioned reversible permeability. In the state of rest the working point remains at C, while when the torch is functioning it runs back and forth along the line BC (strictly speaking it describes a very narrow loop).

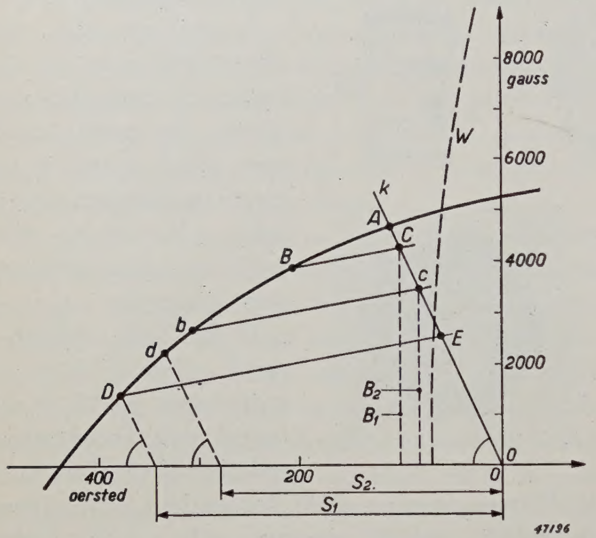

Fig. 6. Demagnetization curve of the magnet steel "Ticonal" 0·8 used in the pocket torch dynamo. In ordinary use the working point of the magnet steel (of a given part in the poles) runs for example back and forth on the line BC. Due to a temporary short circuit this point would fall to D through the strong counter-field S_1. When the magnet is demagnetized in advance to the working line bc and is given correspondingly larger dimensions to obtain the same flux, a weaker counter-field, S_2, occurs upon short-circuiting (where $S_2 : S_1 = B_2 : B_1$), so that the working point only falls to d. The dotted curve W represents, for the sake of comparison, the demagnetization curve of tungsten steel.

This is true, however, only as long as the counter-field due to the current taken off does not become stronger than corresponds to point B. If a short circuit occurs, when a much larger current flows for a very short time, the induction falls for instance to D, the short circuit is ended and the induction ascends along the line DE instead of returning to C. A new working point E is then reached, which may have a much less favourable position. This means that after one short-circuiting the dynamo will no longer produce sufficient voltage, unless the magnet is magnetized anew by means of special devices required for that purpose.

This disastrous effect of a short-circuit can be eliminated in a simple manner by using a somewhat larger magnet and demagnetizing it slightly when assembling the dynamo, for instance to point b in *fig. 6*, so that the working point lies at c [5]). The magnet has to be so much larger as to produce the same flux as before, since under otherwise equal conditions the flux determines the A.C. voltage generated. Also the current upon short-circuiting occurring is the same, but the counter m.m.f. thereby set up is distributed over a greater length of magnet and the demagnetizing field (S_2 in fig. 6) is thus proportionally smaller. The point d reached when short-circuiting occurs will therefore not lie much lower than b and in any case much higher than D. With a suitable choice of the initial state c, the working point may even in the event of a short-circuit still remain on the recoil line bc, so that the short-circuit then causes no permanent change of any kind.

The method described is employed in the pocket torch dynamo in order to exclude the possibility of it being rendered unserviceable by a single temporary short-circuit, although there is very little chance of short-circuiting thanks to the completely closed construction of the torch. The slightly heavier weight of the magnet constitutes no objection, especially since it could be set against the above-mentioned lead disc added to increase the moment of inertia. In this case it would have been of practically no advantage to reduce the amount of magnet steel by substituting one of the still better kinds of magnet steel for the "Ticonal" 0.8 [6]).

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[5]) Point c will only lie on the same line b when the air gap is enlarged in the same proportion as the magnet. In practice this will not be done; the considerations become somewhat more complicated but the conclusions remain the same.

[6]) See, for example, B. Jonas and H. J. Meerkamp van Embden, New kinds of steel of high magnetic power, Philips Techn. Rev. **6**, 8, 1941.

THE VITREOUS STATE

by J. M. STEVELS. 539.213.1

The vitreous state of matter is the solid state of aggregation which occurs when a liquid solidifies without crystallizing. In this article the factors are discussed which exert influence on the tendency of a substance to solidify in the vitreous form. The most important cause of the formation of a glass is an association of the atoms of the liquid which leads to larger and larger complexes upon decreasing temperature of the liquid. Under certain circumstances, discussed in this article, these complexes have practically no tendency to pass over into a crystalline structure. The mass then solidifies in such a way that the arrangement of the atoms, considered over short distances, exhibits much similarity with that in a crystal, while over distances of more than a few atoms there is no regular arrangement. In the case of the glass-forming oxides a detailed study is made of the characteristics of their structure responsible for their tendency to form glasses, following in the main the conceptions of Zachariasen. In conclusion a discussion is given of the inorganic glasses formed by fusing together different oxides. It is shown that a glass can best be composed of a suitable acid oxide as glass-former and basic oxides which lower the temperature of fusion.

Most substances are known in three states of aggregation: gaseous, liquid and solid. In the gaseous state the molecules of the substance have no mutual cohesion, so that a given quantity of it can fill a space of any given form and size. In the liquid state the volume of a quantity of substance is almost independent of pressure and temperature. The form of the space filled, however, is still arbitrary, while in the solid state the form is also fixed.

Given such a description the question immediately arises as to whether it is clear in every case what state of aggregation one is dealing with. If, for example, a liquid is very compressible, its behaviour under high pressure does not differ in character from that of a gas. If, on the other hand, a liquid has a high viscosity, so that it accommodates itself only slowly to the shape of the container, doubt may be felt whether one is not dealing with a solid. It is well known that a gradual change of shape (plasticity) is possible in a solid under sufficiently high pressure. Thus if the states of aggregation of matter were distinguished merely by the characteristic properties just outlined, the state of matter could always be considered more or less as a transitional case between different states of aggregation.

The fact that the states of aggregation of the substances occurring in nature are usually unambiguously determined is thus actually a remarkable phenomenon. The reason for this fact by no means lies in the properties which the substance possesses in each of those states of aggregation, but in a phenomenon which has not yet been mentioned, namely that of discontinuous phase transitions. At very definite temperatures the substance suddenly changes its structure, and with the absorption or giving off of heat it passes over from one state of aggregation to another. The range of existence of the states of aggregation is sharply limited by theses phase transitions, so that all uncertainty is removed.

If we now consider in particular the transition between the liquid and the solid substance, the change in structure consists briefly in the fact that the molecules in the liquid state exhibit a more or less random arrangement, while the solid substance has a definite crystalline structure. Upon further cooling of the solidified material this structure may change one or more times (again with the giving off of heat). It is thus not in principle necessary that a phase transition should be accompanied by a change in the state of aggregation.

The vitreous state

In the case of many substances it is observed that upon cooling the liquid mass solidifies gradually, without there being any question of a phase transition. The viscosity of the liquid increases steadily with decreasing temperature until the deformation of the mass has finally become so difficult that the substance must be called solid. Conversely, upon heating such substances above a certain temperature they do not suddenly become liquid, but only very gradually. Apparently no sudden change of structure occurs during the softening or solidifying.

A substance which behaves in this way is called a glass in the solid state. From X-ray diffraction photographs of glasses it is indeed evident that the atoms exhibit the same random arrangement in the solid state as in the liquid state. This may be due to various causes. In the first place it might be held that the molecules or parts of molecules from which the glass is built up are unsuitable for the composition of a regular crystalline structure. This, however, is a practically unknown phenomenon, at least in inorganic chemistry. It is more likely that the crystalline state does indeed exist but that the molecules are too much hindered in their movements during the solidification to achieve this regular arrangement. Glass is therefore called a supercooled liquid. By this is meant that upon cooling the liquid has indeed passed through the temperature zone of a phase transition but that the phase transition has not taken place. The vitreous state is thus unstable compared with the crystalline state. In certain cases it has actually been observed that the glass begins to crystallize, which is called devitrification.

For the sake of completeness attention must here be called to the difference between glasses and amorphous substances which also possess a random molecular structure but which cannot be considered as supercooled liquids. Certain substances, for example, are obtained in the amorphous state by condensing them from the vapour on a cold surface. The atoms deposited then lose their freedom of movement all at once due to the cooling, and remain at the spot where they happened to be deposited.

Very many substances are obtained in the amorphous state when they are precipitated rapidly from a solution and at not too high a temperature (for example metal hydroxides or oxide hydrates). Such an amorphous substance is also formed by the electrolytic oxidation of aluminium in certain solutions, whereby a porous, very adhesive covering layer of Al_2O_3 is formed on the metal (technically known as eloxal film). Upon examining this surface layer with X-rays no crystalline structure is detected. This means that any possible order of the atoms cannot be more than a few atomic distances.

When does the vitreous state occur?

As already stated, the cause of the occurrence of a vitreous state may in general be sought in the fact that the molecules of the liquid are too much hindered in their movements to attain the crystalline state. The fact that the molecules of a substance which solidifies as a glass are actually less mobile than those of other substances may be concluded from the fact that the molten glasses usually possess a high viscosity. It is very possible that the "molecules" of the glasses in the liquid state are already joined to larger aggregates, which, because of their shape or position, are not capable of being combined into a crystalline structure; crystallization then requires a complete regrouping of the atoms, whereby here and there bonds in the "molecules" must be broken. The process therefore requires a very long time and can only take place completely upon very slow cooling.

A striking example is furnished by the behaviour of sulphur, and especially of selenium, which, when the molten substance is not too slowly cooled, is easily obtained in the vitreous form. Since each Se atom can combine with two other Se atoms by means of strong valence forces, at a relatively high temperature in molten selenium, chains

$$\mathrm{Se - Se - Se - Se - Se - Se}$$

are already formed, which become longer and longer with decreasing temperature. As a result the viscosity of the molten selenium increases rapidly as the temperature is lowered. The forces between neighbouring chain molecules, in contrast to the forces inside a chain molecule, are relatively weak, so that there is little tendency towards crystallization. Only at a fairly low temperature, at which the mass is already extremely viscous, is the state reached where the molecules would take on a regular arrangement. In the meantime, however, the possibility of motion of the chains in the tangled mass has become so slight that this arrangement can only take place very gradually.

If the decrease in temperature takes place fairly rapidly the viscosity quickly reaches such a value that the substance may be considered as solid. The mobility of the molecules has then become practically zero and regular arrangement is then quite impossible.

A type of behaviour similar to that of selenium is encountered in numerous organic substances, for example ethanol (ethyl alcohol), glycerol, glucose, cane sugar and various alkaloids such as brucine and cocaine. In the cases of these substances also the molecules probably join in the liquid state to associated complexes, so that there is little tendency towards crystallization.

In the case of the glasses proper, which are obtained by the fusing of certain oxides or mixtures of oxides, the analogy of their behaviour to that of selenium is less obvious, and for a thorough understanding of the vitreous state it is therefore desirable to investigate the structure of the glass-forming oxides more closely. In the discussion we shall be guided by the work of Zachariasen [1]), who showed that the formation of a glass is connected with certain specific properties of the crystal structure. Zachariasen's rules are found to furnish a satisfactory picture of the behaviour of the oxides, and they may with success be used to prophesy whether a given compound possesses a tendency to form a glass.

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[1]) W. H. Zachariasen, J. Amer. Chem. Soc. 54, 3841, 1932; J. Chem. Physics 3, 162, 1935.

Structure of vitrifying oxides

The most suitable components of glasses, according to general experience, are the oxides of elements such as boron and silicon, which furnish small atoms with a high charge. We may consider these oxides to be built up in the first instance of negative oxygen ions (O^{2-}) and the very much smaller positive ions of boron or silicon (B^{3+} or Si^{4+}). In these cases the force of attraction of the central ion is so great that the "charge cloud" of the neighbouring negative ions is drawn towards that central ion. A treatment which chooses the centre of the negative ions as the position of the negative charge cannot, therefore, lead to quantitatively correct results.

It is, however, very useful for our purpose, *i.e.* for finding the relation between the structure of the vitrifying oxides and their tendency to form a glass.

Just as in the case of selenium, we shall first examine how with falling temperature the particles will combine to larger aggregates. We shall try to explain the way in which this takes place on the basis of two examples, namely from the structure of crystobalite, the crystalline modification of SiO_2 which is stable at high temperatures, and from that of B_2O_3. The structure of crystobalite, which is well-known from X-ray analysis, is shown in *fig. 1.*

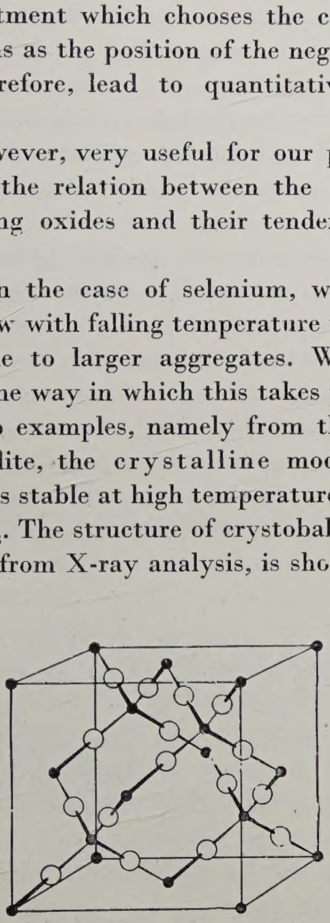

Fig. 1. Crystal structure of crystobalite. Black dots, silicon ions (Si^{4+}); white circles, oxygen ions (O^{2-}). Each silicon is surrounded by a tetrahedron of oxygen ions.

It may be seen that here every Si^{4+} ion is surrounded by four oxygen ions arranged in a tetrahedron. Each of these oxygen ions, however, is not only bound to one positive ion, but at the same time forms a part of the surroundings of a neighbouring positive ion. In this way the structure can be extended in all directions, so that the whole crystal lattice is held together by valence forces.

In the case of boron trioxide the boron ion is surrounded by only three oxygen ions. The structure of boron trioxide and that of silicon dioxide thus contain triangular and tetrahedral groups of ions, respectively, which are shown in *fig. 2.* It may be seen that the space between the oxygen ions only offers room for an ion of much smaller dimensions and it is therefore obvious that these structures will only occur in the presence of very small positive ions.

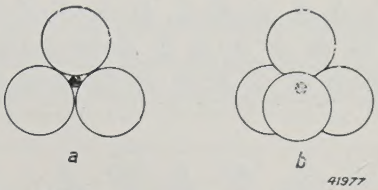

Fig. 2. The most commonly occurring ion groups in the crystal structures of the oxides of glass-forming ions:
a) triply charged positive ion with three surrounding oxygen ions (the case of B_2O_3),
b) quadruply charged positive ion with four surrounding oxygen ions (the case of SiO_2).

Considered purely geometrically, the silicon ion or the boron ion could be also surrounded by a larger number of negative oxygen ions, for instance six. Since the interstice between 6 negative ions, however, is appreciably larger than the highly charged central ion itself, this coordination is not stable from the point of view of energy; due to the attraction by the positive charge the negative ions are drawn as close as possible to the central ion, and this results in a number of negative ions being pushed out of the first shell around the central ion. The result is the grouping of the oxygen ions in triangles or tetrahedra already mentioned.

The way in which these groups of ions can combine to a crystal is shown in *fig. 3*, in which a number of regular structures — for the sake of simplicity plane structures — are reproduced which are derived from the triangular group.

The distinctive difference between fig. 3*a* on the one hand and figs. 3*b* and 3*c* on the other is that in case *a*) each negative oxygen ion belongs to three adjacent groups, while in cases *b*) and *c*) only two neighbouring groups are joined by each oxygen ion. Which of these two possibilities will be realized depends upon the charge of the positive ion. If one assumes that the positive ion — like the oxygen ions — is doubly charged, it is evident that the negative charge of the ion triangle is three times as large as the positive charge of the central ion. A neutral whole can then only be obtained by having each oxygen ion belong to three different groups, so that a structure like fig. 3*a* will be formed. If, however, the positive ion has a triple charge, the negative charge of the ion triangle is only twice as large as the positive charge, so that every oxygen ion will be coupled to only two positive ions. Rarefied structures of the nature of figs. 3*b* and *c* then result.

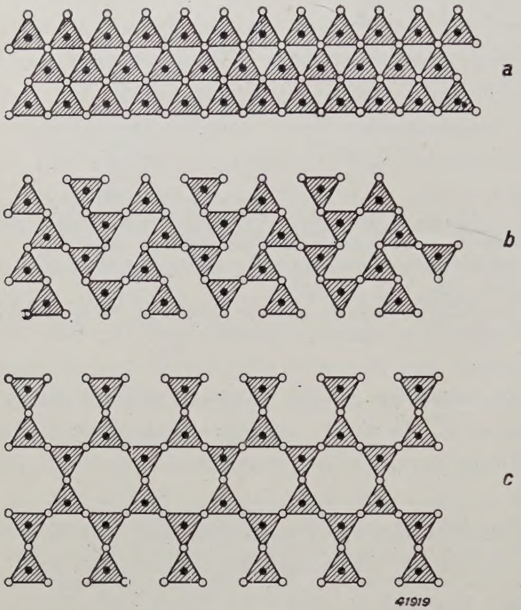

Fig. 3. Diagram of the way in which crystal structures can be formed from triangular ion groups in a flat plane. In case *a*) three ion groups come together at each angle, in the cases *b*) and *c*) only two ion groups. Case *c*) differs from case *b*) by the more symmetrical arrangement of the positive ions and by a more rarified structure.

The fact that the presence of highly-charged positive ions leads to a rarefied structure may seem paradoxical, but it can be explained in principle in the following way. If we are concerned with polyhedra consisting of m doubly-charged negative oxygen ions ($m = 3$ for a triangle, $m = 4$ for a tetrahedron), each of which "belongs" to n positive ions (which bear a charge p), then for the sake of electrical neutrality $2/n = p/m$. Thus for a given kind of polyhedron p, n is a constant, in other words a high charge p on the central positive ion results in a low value of the coordination number [2]) n of negative ions, and thus in a rarefied structure.

It might be imagined that the structure *b*) is more advantageous from the point of view of energy than *c*); it has indeed a greater density and thus yields more to the attractive forces between the particles. This opinion, however, is found to be incorrect. A structure like 3*b* is only possible when each positive ion is surrounded by other positive ions in an only partially symmetrical manner, so that the mutual distances between some of these ions are small. Now it is just these neighbouring positive ions which are not completely screened from each other by the surrounding negative charge. They will therefore repel each other strongly, which makes the structure less stable. The result is that the completely symmetrical configuration according to fig. 3*c* is more favourable than 3*b* from the point of view of energy. This can also be expressed by saying that the repulsive forces between the highly charged positive ions "swell" the lattice until a symmetrical, although also a rarefied, structure is obtained.

The same forces which are active in the crystalline state are also already active in the liquid state of the oxides in question. Perfectly regularly arranged lattice structures are then not yet present, but the first surrounding of every positive ion by negative ions will not differ much from that in a crystal. Here also the electrostatic forces of the ions will result in ion groups joining together to larger aggregates by means of common oxygen ions. As far as the mutual connection of neighbouring groups of ions is concerned, these aggregates will exhibit much similarity with the final crystalline structure; over longer distances, however, the regular arrangement will not be maintained.

For the crystal types of figs. 3*a* and *c* the arrangement in the liquid state is now shown diagrammatically in *fig. 4*. In the attempt to construct such a figure it is immediately obvious that these two cases

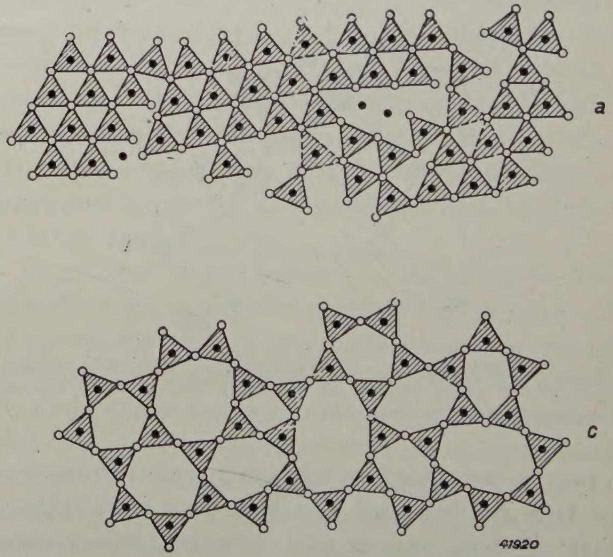

Fig. 4. Diagram of a liquid in which association occurs according to the structures of fig. 3*a*) and *c*), respectively. In case *a*) if there is no completely regular arrangement there must be unsaturated valences; in case *c*) on the other hand the non-regular state differs from the regular state only by slight differences in the valence angles. Therefore in case *c*) there is little gain in energy to be obtained by making a regular arrangement.

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[2]) This term is generally used to indicate the number of immediate neighbours (atoms or ions) possessed by a given atom (or ion).

behave quite differently: in the case of lattice type *a*) one has only the choice between the perfect crystal lattice and a structure in which the bonds between neighbouring ion groups are partially broken, whereas in the case of type *c*) quite irregular structures may be formed by slight changes in the valence angles (which always occur due to thermal agitation). Since in the case of *ionic bonds* the valence forces possess no pronounced preferred direction, the irregular structures mentioned are practically as favourable from the point of view of energy as the ideal crystalline structure.

From these considerations it follows that substances with lattices of the type *c*) exhibit a behaviour like that of selenium upon solidifying. Since the binding forces between the ions are very large, association will already occur at a high temperature, and it will lead to a considerable increase of viscosity with decreasing temperature. The associated groups have then indeed no crystalline character as yet, but as far as energy is concerned they are not much less favourable than the crystal structure, so that their tendency towards crystallization is relatively small. Crystallization therefore only begins at such a low temperature that the viscosity of the material very much retards it. When the cooling is not very slow crystallization fails entirely to take place and a glass is formed.

Generalization of the condition for vitrification

In the above the vitrification of the oxides has been explained by the possibility of forming irregular structures in which the valence forces — except for a small change in the valence angles — are just as effective as in the crystal structure. We have already seen that rarified structures best satisfy this condition; in particular it was found that vitrification was impossible in the case of a structure of the type of fig. 3*a*.

The general formulation of the characteristics which the structure of an oxide must possess in order to be able to form a glass is in this way reduced to a geometrical problem. This problem is quite complicated since it must be treated not in a plane but in three dimensions. We shall not go into the details here, but only summarize the practical results in the following four rules.

1) Every oxygen ion must be bound to not more than two positive ions which must be highly charged and small.
2) The number of oxygen ions which surround such a positive ion may not be too large or too small (3 or 4).
3) The ion groups adjacent to each other may have common corners but no common edges or faces.
4) There must be ion groups which have at least three oxygen ions in common with neighbouring ion groups.

Some of these rules (especially the first) already follow from the discussion given by us of the plane case. Others can be verified by a consideration of spatial structures.

These conditions, which were discovered by Zachariasen, are always found to be satisfied in the case of the glass-forming ions, and conversely it may be said that every oxide which satisfies them is able to form a glass. These considerations can also be applied to other compounds related to the oxides. Thus, for example, it follows for the fluorides that only beryllium fluoride can be obtained in the vitreous state, which is actually found to be confirmed. As an illustration the structures of BeF_2 and CaF_2 are shown in *fig.* 5, and it is evident that the last mentioned compound does not satisfy the first three conditions of Zachariasen but satisfies the fourth.

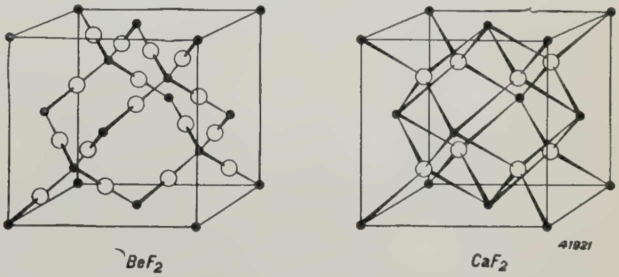

Fig. 5. Crystal structures of the fluorides BeF_2 and CaF_2. White circles F^-ions, black dots Be^{2+} and Ca^{2+} ions, respectively. In the first-mentioned structure, which is identical with that of crystobalite, the conditions for the formations of a glass are satisfied, which is not the case with the last-mentioned: the ion groups are in contact not only at corners but over whole surfaces, and each fluorine atom belongs to more than two ion polyhedra.

The fluorine ions here play the same part as the oxygen ions in the case of oxides.

Survey of vitrifiable oxides

In the foregoing we have seen that the rarified structures necessary for the formation of a glass can only be obtained when the positive ions have a small diameter and a high charge. In the case of the triangular O^{2-} groups it was found that the positive ion must be at least triply charged; for tetrahedral O^{2-} groups, which occur much more often in three-dimensional structures, a minimum charge of four follows in the same way. We may therefore expect that the elements of the fourth and fifth columns of the periodic system of the elements will be the most suitable as “glass formers”.

An experimental investigation has confirmed this expectation. In *fig. 6a* the elements are indicated which form glasses according to experience and also according to Zachariasen's rules. The position of the cations in the periodic system (fig. 6b) agrees perfectly with the expectation expressed.

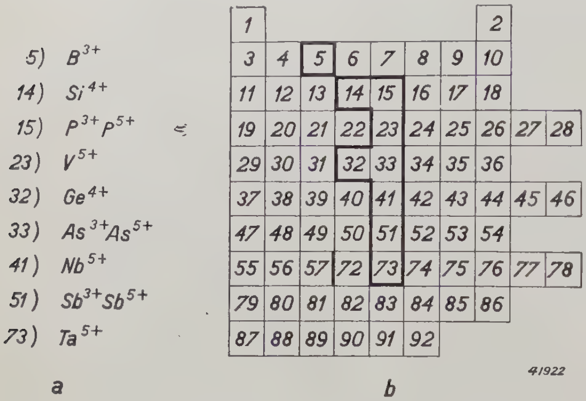

Fig. 6. *a*) List of glass-formers, *b*) position of the glass-formers in the periodic system of the elements. The glass-formers are to be found chiefly in the fourth and fifth columns.

The most important glass-forming element is silicon. Its oxide SiO_2 occurs in four modifications which are stable in different temperature regions. In the order of increasing stability temperature these modifications are β-quartz, α-quartz, tridymite and the already mentioned crystobalite.

In all the modifications the silicon ion is surrounded by a tetrahedron of oxygen ions, but there is a difference in the way in which the tetrahedra are grouped around each other. In addition to the crystalline modifications there is also a vitreous modification, so-called quartz glass. From X-ray diffraction photographs it has been found that this vitreous SiO_2 has a crystobalite-like structure. This structure is actually nothing else than the three-dimensional extension of the rarified plane structure which was built up in fig. 3*c* with the help of triangles. Just as with that structure, it is possible by means of slight changes in the valence angles to obtain an arrangement which, considered over long distances, is without regular order and represents a vitreous state. In the case of other glass-forming ions of the fourth and fifth columns of the periodic system similar structures are obtained consisting of tetrahedral ion groups.

In vitreous B_2O_2 every B^{3+} ion is surrounded by three O^{2-} ions, in other words the structure is composed exclusively of triangles [3]). For the sake of completeness, however, it should be noted that in most borate glasses, in addition to these triangular O^{2-} groups of ions, tetrahedral groups also occur.

Inorganic oxide glasses

If a glass is made up of the oxides of different elements, as is often done in order to obtain a lower melting temperature, only one of the oxides need be a glass-forming oxide. The cations of the other oxides take up positions in the large cavities of the rarified structure and can thereby make solidification more difficult. As a result the temperature of fusion becomes lower and the chance of forming a regular crystalline structure smaller. As an example we may consider the glasses which are formed when positive metallic ions, such as calcium, barium, lead, etc., are taken up in the cavities of the silicon oxide network. Since the whole must remain electrically neutral, the number of negative oxygen ions must of course also be increased. This is done by breaking the connection between neighbouring oxygen tetrahedra at a number of spots, a bridging oxygen ion of two neighbouring groups being replaced in each case by two non-bridging oxygen atoms. The structure which results in this way is shown in *fig. 7*, a plane diagram being given for the sake of simplicity. The grey circles of different sizes represent different metallic ions. By varying quantities and combinations of these ions it is possible to obtain many thousands of different glasses with very divergent properties.

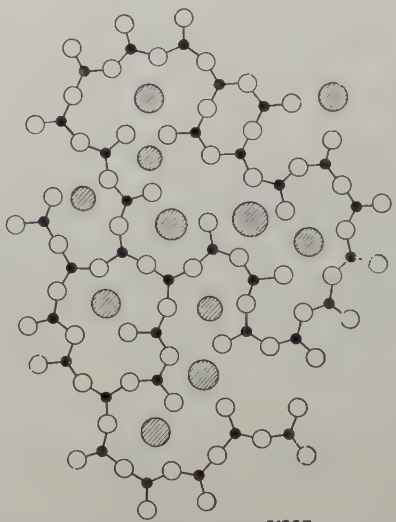

Fig. 7. Schematic representation (in a plane) of the structure of a glass consisting of a glass-forming oxide and different metallic oxides. Black dots positive ions of glass-former, white circles oxygen ions, grey circles different metallic ions. (Borrowed from B. E. Warren and A. D. Loring, J. Amer. Chem. Soc. **18**, 269, 1935).

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[3]) The spatial network of vitreous B_2O_3 consists of "two-dimensional" structures of the type of fig. 4c, which lie practically at random with respect to each other but between which valence bonds are present.

Compared with the glass-forming ions the metal ions possess a smaller positive charge and a much greater diameter. This means, therefore, that the glass-forming ions possess a much stronger electric field on their surface. It is remarkable that this difference is also manifested chemically in a very typical way: the glass-forming oxides behave as acid oxides, while the metallic oxides behave as basic ones. In general it is found possible to consider the field at the position of the centre of the adjacent oxygen ion as a measure of the "acidity" of a positive ion [4]). One may then say that a glass can best be composed of an acid oxide as the glass-former proper and one or more basic oxides as fluxes, the cations of which must fill the cavities in the rarified structure.

What will happen if, as admixture with the SiO_2, metallic oxides are used of increasingly weaker basicity or increasingly stronger acidity? As long as the admixture is limited to the genuinely basic oxides (Na_2O, CaO, PbO, etc.) the vitreous state is tenable. If one continues in the series, however, the cavities of the glass structure will then be more and more strongly drawn together by the forces of attraction of the metallic ions, until finally the glass structure becomes untenable. A demixing of the metal oxide and the SiO_2 then occurs: each of the two kinds of positive ions surrounds itself with oxygen ions according to its own coordination number and forms a corresponding characteristic lattice structure, with as result a strong tendency to devitrification. This case occurs, for example, when titanium oxide (TiO_2) is added to SiO_2. When one passes on to the oxides of still higher acidity, one arrives at the actual glass-forming oxides, such as CeO_2, B_2O_3, P_2O_5. The tendency towards devitrification now disappears and a homogeneous vitreous structure is obtained again. Apparently these glass-forming ions resemble the silicon ion so much in coordination number and valence that they can form a common glass structure with it.

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[4]) See A. Dietzel, Naturwiss. **23**, 537, 1941; Z. Elektrochem. **48**, 8, 1942.

A DIRECTING INSTRUMENT FOR THE OPERATIVE TREATMENT OF FRACTURES OF THE NECK OF THE FEMUR

by G. J. van der PLAATS and A. VERHOEFF. **616.718.42-001.5-089.2**

A fracture of the neck of the femur is usually treated operatively, the parts of the broken bone being joined firmly together by hammering in a hollow steel nail after a guiding needle has been bored into the bone. In performing such an operation the surgeon is faced by the problem of directing the guiding needle in such a way as to obtain exactly the desired position of the pin, which has been determined in advance by means of X-ray photographs. Philips has constructed a directing instrument for this purpose which, compared with other apparatus for the same purpose, has the advantage, *inter alia*, that the necessary adjustments and settings indicated by the X-ray photographs can all be made in advance of the actual operation. The operation is thereby considerably shortened, while in addition, except for the carrier of the guiding needle, the instrument need not be sterilized.

Conservative and operative treatment of fractures

In general the surgical treatment of bone fractures may be confined to reduction of the fracture, making every attempt to fit the fragments into their proper places. If this reduction is successful and the position remains correct, which should be checked by X-ray examination, the body itself provides for the further repair by the formation of new connective tissue which later calcifies (callus formation) and makes a firm joint (consolidation).

There are, however, cases where this so-called closed or conservative treatment of a fracture is inadequate, either because there is insufficient callus formation or because this takes place so slowly that the patient has to be confined to bed for months, with the danger, so familiar to doctors, of secondary pulmonary or other disorders. A classic example of this is the fracture of the neck of the femur (fractura colli femoris). This fracture occurs most often with eldery people due to a fall on the side, and since callus formation in the femoral neck generally leaves much to be desired and the fracture in question naturally makes the use of the legs impossible, with the closed treatment healing, if occurring at all, requires a very protracted immobilization of the patient.

For this type of fracture, therefore, it has long been the custom to apply a different method of treatment. After reduction the broken bone is exposed operatively and the fragments are joined firmly together by driving in a triradiate nail. The X-ray photograph of *fig. 1* shows an example of such a "femur neck nailing". When the fracture has been "nailed", the patient can usually be up and about after a few weeks. In cases making favourable progress callus is formed in spite of the leg being used, and consolidation takes place around the pin. The nail, for which nowadays a special stainless steel is mostly used — formerly a piece of fibula was taken from the patient's calf — can subsequently be removed by a simple operation.

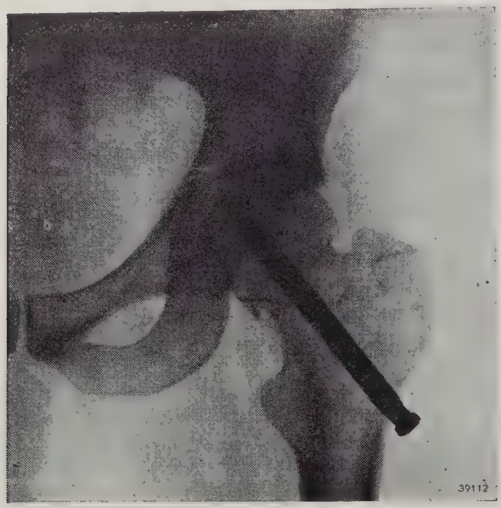

Fig. 1. X-ray photograph of a fractured neck of a femur with nail driven in.

Directing the nail in "femur neck-nailing"

The pin has to be driven from the outside of the femur through the neck and the centre of the femoral head (fig. 1). The precise position that the nail should ultimately occupy can be ascertained by the surgeon from the X-ray photographs of the broken bone after reduction .The problem in this method lies in the directing and driving in of the pin so that exactly the desired position will be obtained.

The approximately 8 mm thick nail cannot be driven in without a guide. The pin is therefore made hollow and driven over a thin guiding needle made of knitting-needle steel, which is previously bored into the bone and drawn out after the nail has been driven in. The problem of directing the nail is of course not thereby solved, but it is somewhat facilitated in that it is transferred from the nail to the much thinner guiding needle. Any error in the direction chosen can be corrected by inserting other needles until the photographs show that the needle is in the right position. During recent times in fact the procedure has usually been such that the needle is directed visually with the sole assistance of several reference points and requirements of an anatomical nature, the needle seldom being placed in the correct position at the first attempt. The result was a long operation (with long narcotization) and the accompanying risk of complications.

Attempts have repeatedly been made to improve upon this by constructing directing instruments to make it possible to insert the guiding needle in the correct position at the first attempt. Usually these directing instruments had to be aligned with respect to the patient's body by fixing them to a separate supporting pin driven at some point into the femur, while of course the greater part of the instrument had to be sterilized and all the adjustments had to be made during the actual operation (with the bone exposed). It is not surprising that most surgeons have abandoned such aids, for their attention was too much distracted from the operation itself, which leaves no time and attention to be devoted to complicated adjustments; the surgeon can barely spare the time taken in waiting for and studying the X-ray photographs.

The new directing instrument

The drawbacks mentioned are avoided in a new directing instrument for "hip-nailing" which has been constructed by Philips[1]). In order to reduce appreciably the time taken for the operation this instrument has been designed so that all the manipulations of fixing and adjusting can take place prior to the operation proper. This instrument is not fixed to the bone itself. Instead, bone and instrument are both fixed with respect to a third point, the operating table, *viz.* a stand fastened to it. Furthermore the directing of the needle is reduced to three adjustments, which can be derived in a simple manner from the X-ray photographs made in advance and necessary in any case for checking the success of the reposition.

The principle of the instrument is clearly illustrated in *figs. 2a* and *b*. The needle to be bored into the bone is placed in a needle conductor, which can be moved around a horizontal axis (by sliding along the arc *C*) and around a vertical axis (by turning the arm *B* about a hinge *S*), in such a way that the needle is always directed towards the same point (*O* in fig. 2*a*). This point lies at a fixed distance vertically under the hinge. Since, however, the hinge is fastened to an arm on a stand (*A* in fig. 2*b*), which in turn can be rotated about the vertical stand, moved up or down the latter and also varied in length, the point *O* can be determined at any arbitrary point with respect to the operating table. The surgeon has to make the point *O* coincide with the centre of the femoral head while the patient is fixed on the operating table. Then the guiding needle always points to that centre.

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[1]) The practical application of the method has been tried under the direction of the first named author in the Hospital "Calvariënberg" near Maastricht (Netherlands) and has already jielded good results.

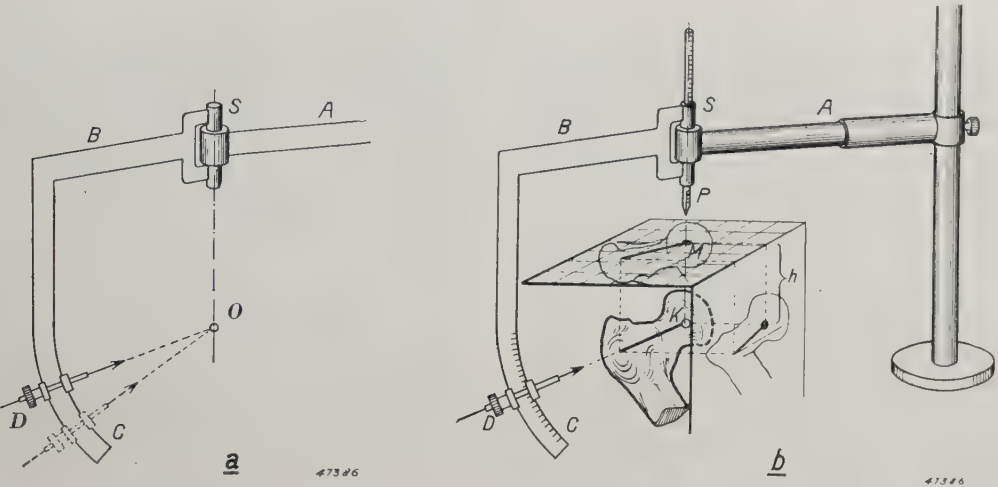

Fig. 2. Principle of the new directing instrument.
a) *D* needle conductor with the guiding needle, *C* arc with graduated scale, *B* arm rotatable about the hinge *S*. Upon the rotation of *B* and the sliding of *D* along *C*, the guiding needle always remains directed towards the point *O* lying at a given distance vertically below *S*.
b) Bij means of radiographs the fractured femoral neck is projected upon a horizontal and a vertical plane. *K* centre of head of the femur, *M* projection of this on the horizontal plane, *h* depth of *K* under *M*. *P* vertical hinge-pin graduated and moveable in the hinge *S*. *A* telescopic arm of stand. When *P* is set at a scale division corresponding to *h* and the extremity of *P* brought to the point *M*, the fixed point *O* to which the guding needle is pointed lies at the centre of the head *K*. In both projections the desired position of the nail is drawn in, and the needle conductor can then be set at the angles found.

After that it only remains to adjust the angle in the horizontal plane and that in the vertical plane.

In order to carry this out a horizontal and a vertical projection of the femur is made by means of an antero-posterior (with respect to the patient) and a lateral X-ray photograph. For the sake of simplicity it is assumed that the two planes of projection are the two planes indicated in fig. 2*b*, which are in a fixed relation to the operating table and which contain the axes of a three-dimensional rectangular system of coordinates. The projection of the centre of the femoral head on the horizontal plane is indicated by *M*. The projection of the centre on the vertical plane lies a distance *h* below the horizontal plane of projection. The arm *A* is now so adjusted that the extremity of the pin *P* of the hinge, which slides vertically in the hinge *S* and is provided with a scale, stands at the point *M*. The hinge is at the zero point of the scale when the end of the hinge-pin coincides with point *O*, that is the fixed point towards which the guiding needle points. When the hinge-pin has previously been moved up so far that the hinge stands at the scale mark *h*, the fixed point *O* for the guiding needle then lies a distance *h* vertically below point *M*. The first adjustment is thus completed. On the two X-ray projections of the femur, on which the desired position of the nail is sketched in, the angles can be found at which the needle conductor has to lie. The latter can then be adjusted to these two angles by means of a graduated scale on the arc *C* and by setting the rotating arm *B* parallel to the horizontal projection of the desired direction [2]).

Practical application

The horizontal plane with system of coordinates on which the femur must first be projected is realized by a horizontal wire grid, which can be swung around the stand column of the instrument and which is photographed together with the neck and head of the femur in a position just above these. *Figs. 3a* and *b* show the positions for taking the two radiographs, the patient being replaced by a skeleton for the sake of clarity. On the antero-posterior radiograph the point of projection M of the centre of the femoral head is drawn in in the grid; the depth of this centre below the grid is determined from the lateral radiograph.

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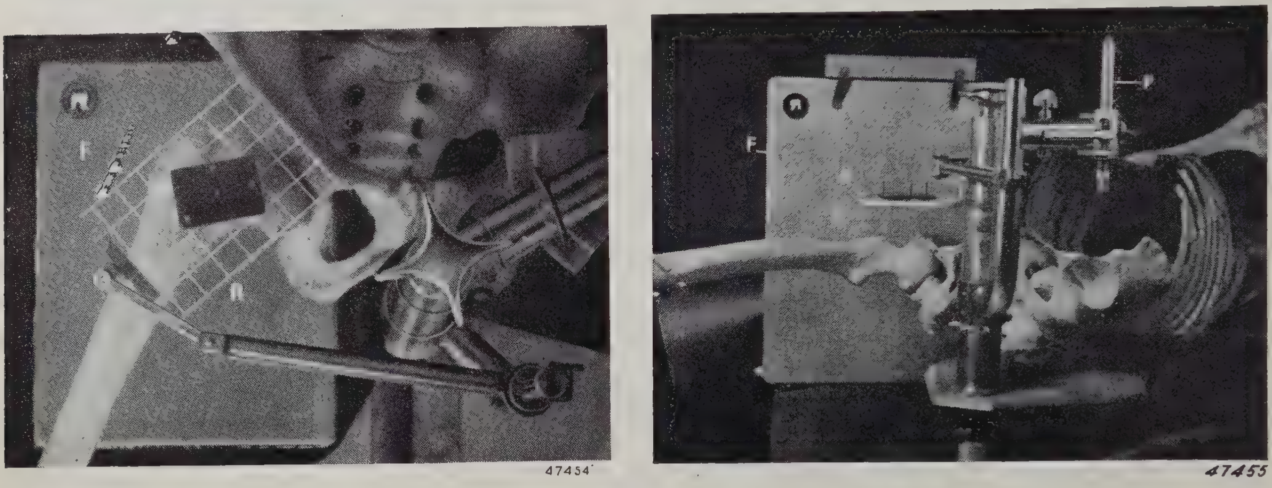
[2]) The angle measured in the lateral X-ray photograph is exactly equal to the required angle on the arc *C* only when the vertical plane of projection is parallel to the plane of *C* (*i.e.* parallel to the guiding needle) and the centre of projection (*i.e.* the focus of the X-ray tube) lies at the same height as the centre of the head of the femur. In the case of small deviations from these conditions, however, the difference is very slight, so that it is sufficient to adjust the X-ray film for the lateral exposure parallel to the femur visually and the X-ray focus approximately at the desired height.

In the case of the lateral radiograph it is necessary to make sure, with the help of a spirit level on the film cassette, that the upper edge of the film is exactly horizontal (fig. 3*b*). The angle of the nail measured with respect to this edge gives the adjustment of the needle conductor on the arc.

Having thus obtained all the necessary data, the directing instrument can be adjusted. In *figs. 5* and *6* two stages of this process are shown. The hinge-pin is moved along to the correct scale mark and set on the correct point (M) of the wire grid. By means of a pointer inserted in the hinge-pin underneath, the arm B is turned to the correct



a *b*

Fig. 3. Situation for taking the antero-posterior (*a*) and the lateral (*b*) X-ray photographs. The patient is represented by a skeleton. The film cassette F with the X-ray film and the wire grid R serving as horizontal plane of projection may be seen. On this grid is a plate with various lead rods as markers for the corrections to be made. In the foreground in photograph (*b*) is the column of the stand, which is fixed to the operating table and with respect to which the patient is secured immovably. On the arm of the stand to the right is the hinge with hinge-pin P. On the film cassette is a spirit level for setting the upper edge of the film exactly horizontal.

Each of these two figures needs a **correction**. Let us first consider the lateral aspect. Due to the unavoidable enlargement obtained in making an X-ray shadow image because of the divergence of the rays, the depth (h') measured on the radiograph is too large (see *fig. 4a*). For the correction three lead rods 2 cm long are set up vertically on the grid (clearly visible in fig. 3*b*), which rods are also shown enlarged on the photograph, but enlarged to different degrees according to their distance. On the antero-posterior radiograph it is ascertained which rod lies closest to point M, and the enlargement of that rod then furnishes the correction factor for deriving from h' the true depth h.

The correction of the other figure, the projection of the centre of the femoral head on the wire grid in the antero-posterior radiograph, is less important. This projection (M_1) is only identical with the desired point M vertically above the centre of the head when the X-ray focus was also directly above the centre during the exposure; see fig. 4*b*. The usually very small and often negligible correction is found by placing a mark on the grid directly under the focus, for instance a small hole in a horizontal lead rod. If this hole is found to be projected at a distance d from the centre of the head on the radiograph, it follows from the figure that point M on the grid must be located a distance $x = d \cdot h/f$ in the opposite direction from M_1 (f is the measured distance from focus to film).

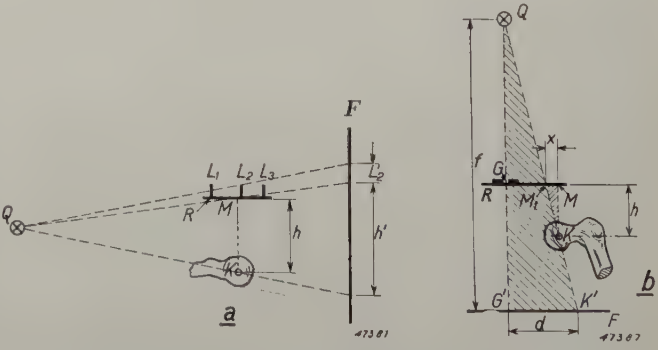


Fig. 4. Explanation of the required corrections.

a) In the lateral radiograph. Q focus of the X-ray tube, K centre of the head of the femur, F film, R wire grid. L_1, L_2, L_3 lead rods. The enlargement of the rod L_2 gives the correction factor for determining the true depth h from h'.

b) In the antero posterior photograph. Q, K, F and R as in *a*). G small hole in horizontal lead rod as marker for point directly below Q. The distance x from the desired point M to the erroneous projection M_1 follows from $x : h = d : f$, due to the similarity of the cross-hatched triangles.

position according to the horizontal projection of the position required for the nail [3]). In fig. 5 it will be seen that the arc *C* and the needle conductor are not shown. Since these parts will be close to or even in contact with the area of the operation, they have to be previously sterilized together with the other instruments necessary for the operation. Only after all the adjustments are completed and the area of the operation is disinfected and covered sterilely, are they passed over the arm *B* and fixed as shown in fig. 6. The needle is then fixed at the correct scale division of the arc.

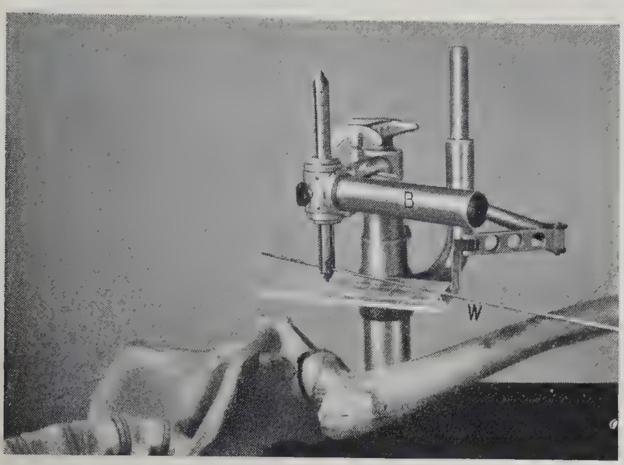


Fig. 5. After the end of the hinge-pin has been brought to the correct point on the wire grid, by means of a pointer *W* inserted in the hinge-pin, the latter, which is made to slide in a slot and therefore always carries the arm *B* with it, is turned to the correct direction, *i.e.* according to the desired direction of the nail drawn on the wire grid in the horizontal projection. The arc with the needle conductor, which have to be sterilized, are not shown.

After this the actual operation begins. By sliding the needle conductor as far as the surface of the skin of the thigh the surgeon determines the correct position for the incision to be made, so that the wound can be kept as small as possible. The arc with the needle conductor can then be turned upwards 180° in order not to be in the surgeon's way. After the bone has been exposed and the hard superficial layer has been chiselled or bored away, the arc is definitely fixed in the directing position, the needle conductor, which is provided with two sharp points, is tapped a few mm into the bone and the guiding needle proper is bored in to the required depth — which has also been deduced in the obvious manner from the X-ray photographs. The needle conductor and the whole directing instrument are then removed, the hollow nail is passed over the guiding needle and hammered into the bone with a hollow punch.

Before this last step is taken two new X-ray photographs could, of course, be made to make sure that the guiding needle has taken the desired direction in the bone. Experience has shown, however, that there is really no need for this, unless meanwhile the position of the patient should have unexpectedly changed, which is not at all likely. After the nail has been driven in, however, another couple of radiographs is always taken to check whether the nail has been driven in to exactly the desired depth ; if the photograph shows it to be necessary the surgeon can drive the nail slightly farther in.

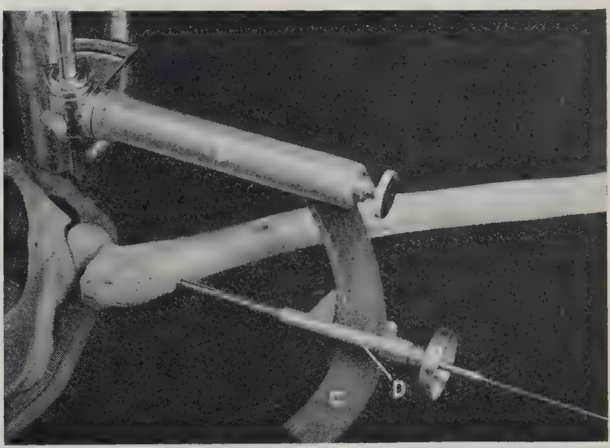


Fig. 6. Arc *C* and needle conductor *D* have been put in place, the needle conductor has been tapped into the bone and the guiding needle can now be bored in.

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[3] This direction, too, only agrees exactly when the focus happens to be exactly vertically above the centre of the head of the femur. The correction required for the deviation from this condition, however, is so small as to be practically negligible for our purpose.

ILLUMINATION INTENSITY IN OFFICES AND HOMES

by A. A. KRUITHOF and H. ZIJL.

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An attempt is made in this article to solve the problem of the most suitable illumination intensity for the activities of office and home. Use is made not only of data about visual acuity and contrast sensitivity of the eye, but also of tests of the fatigue resulting from long-continued reading. The conclusion is that upon increasing the illumination intensity from 10 to 100 lux a very considerable improvement can be obtained, from 100 to 1000 lux still an appreciable improvement and above that only a slight improvement. Consideration is given to a method for finding the optimum illumination level for practical office lighting, while it is pointed out that experience has shown 100 lux to be the necessary minimum illumination intensity. In conclusion the reasons are discussed for the fact that in homes almost invariably much lower illumination intensities are used than are advisab e for ordinary household tasks; possibilities of improvement are suggested.

The human eye possesses a remarkable power of adaptation: it can discern objects in the brightest sunlight under an illumination intensity of maybe 100,000 lux and on moonless starry nights when the illumination intensity is only 0·0003 lux. Vision under such extreme conditions, however, is of course difficult and defective. Man, unwilling blindly to accept unfavourable natural conditions, looks for means of correction: in bright sunlight he puts on dark glasses, at night he uses a lantern, in order in both cases to adjust the amount of light available for the eye to more suitable values.

The region of the "more suitable" values of illumination intensity, where the eye usually works without extra assistance, is still extremely wide: it extends from a few lux, the level employed in street lighting — motor car drivers ordinarily switch on their head-lights as soon as the illumination intensity on the road falls below 3 to 4 lux — to the more than 10,000 lux necessary in a film studio. These "more suitable" values are certainly not the "most suitable" ones: if only the requirement of light for the eye is considered, higher intensities would certainly be employed in the first case and lower intensities in the second. In the first case considerations of economy chiefly determine the upper limit, while in the second case it is the light required by photographic material which determines the lower limit.

In all cases where illumination is necessary such limitations will be manifest. But let us suppose that for a while these limitations were absent. For each type of activity that has to be carried out there would be a more or less accurately determined value of the illumination intensity at which that activity can "best" be carried out. This value would probably differ somewhat for different persons.

There can be no doubt that it is important to find out what are the most suitable values of the illumination intensity.

On the basis of a number of investigations, part of which have been published during recent years, we shall in this article attempt to answer this question. We shall confine ourselves to the activities ordinarily performed in offices and homes. At the same time the economic, technical and other (chiefly esthetic) considerations will be discussed which are the cause that the illumination levels actually used in practice remain very far below the "most suitable" ones.

However, before we go farther into the effect of the illumination level, it must be emphasized that illumination intensity alone is of course not sufficient to characterize an illumination. The quality of the illumination is also of very great importance, and this factor is determined by such features as the degree of diffuseness of the light, the distribution of the illumination over ceiling, walls and working surface and the spectral distribution of the light. We shall discuss the influence of these factors only incidentally and very briefly. For our discussion we shall simply start from the assumption that all the factors mentioned have been chosen as favourable as possible; in particular we shall limit the discussion of practical illumination to those cases in which the fixtures used are constructed in such a way that the disturbing and harmful phenomenon of glare cannot occur.

Factors characterizing the required performance of the eye.

In every human activity the task of the eye comes down to distinguishing some detail against a given background under the given illumination intensity. In reading printed matter, for example, the details are formed by the printed letters, in drawing by the pencilled line, in sewing by the peculiarities of the weave of the material, while in the first two cases the background is a sheet of paper and in the third it is the material as a whole.

The requirements made upon the eye in the different activities can be characterized by the following quantities:

1) the size of the detail to be observed, or more precisely: the angle of vision subtended by the detail under observation;
2) the contrast between the detail and the background given by the ratio of the coefficients of reflection [1]);
3) the time available for the observation (for instance, in sewing the time necessary to find the spot to insert the needle);
4) the length of time during which the activity is continuously performed.

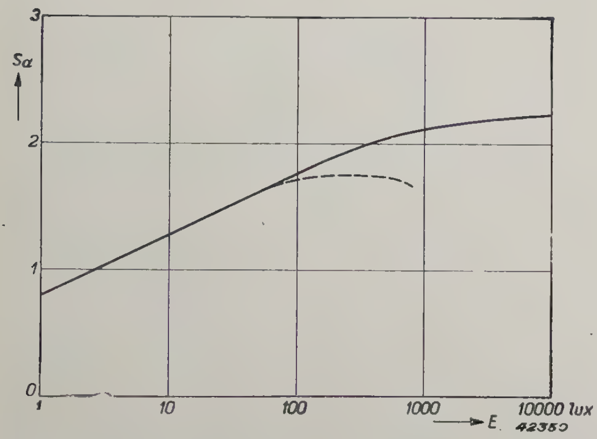

Fig. 1. Visual acuity S_a of an average observer as a function of the illumination intensity E of the background. The background is "white" (reflection coefficient $\varrho = 0{\cdot}75$), the detail observed "black" ($\varrho = 0{\cdot}04$). In the case of the continuous-line curve the surroundings are just as bright as the background; in that of the broken-line curve the surroundings are quite dark. The curves are obtained by a combination of data of Eguchi, Lythgoe, Schober, König. For lower reflection coefficients of the background the experimental results are also valid when account is taken of the fact that it is not the illumination intensity but the brightness which determines the threshold sensitivity of the eye.

Each of the first three quantities, angle of vision, contrast and time of observation, must exceed a certain (minimum) value (depending on the other circumstances) in order to make an observation possible. If the angle of vision must be at least a minutes, the contrast at least $c = B_1 : B_2$ (B_1 = the brightness of the detail, B_2 = that of the background), the time of observation τ seconds, then $S_a = 1/a$ is called the visual acuity, $S_c = {}^1/_2\,(1+c)/(1-c)$ the contrast sensitivity and $S_w = 1/\tau$ the speed of observation of the eye.

The threshold values mentioned depend very much upon the intensity of illumination. A consideration of this relation will furnish us with a first indication about the desired illumination levels. Meanwhile the effect will become evident of the other characteristics of the illumination, such as the colour and distribution of the light and especially of the brightness of the surroundings, for instance of the walls of the room.

In *fig. 1* the visual acuity *Sa* of an average observer, determined by measurement under the circumstances given in the text for the figure, is shown as a function of illumination intensity. It may be seen that up to about 1000 lux visual acuity increases rapidly, while above 1000 lux it increases only slowly. The broken-line curve shows how the performance of the eye decreases when the brightness of the surroundings is too low.

In *fig. 2* analogous curves are drawn for the contrast sensitivity S_c. Let us first consider curve *1*, which is the most important for us. Here also a rapid increase in the performance of the eye is observed when the illumination intensity is increased to the region of 1000 lux, while at still higher illumination intensities the increase becomes very slight. Curves *2* and *3* prove again the harmful influence of too dark as well as too bright surroundings; in the latter case this is a consequence of glare. Curve *4* is recorded with a larger test

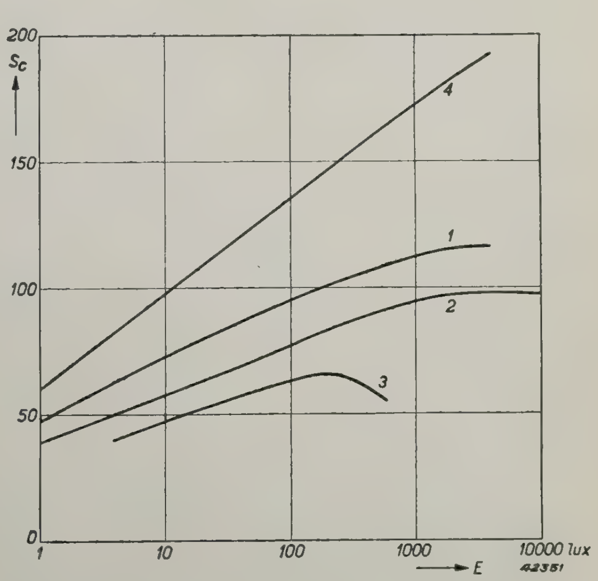

Fig. 2. Contrast sensitivity S_c as a function of the illumination intensity of the background. In the case of curves *1*, *2* and *3* the test object has a diameter of 1°, while the surroundings are, respectively, about equally as bright as the background, completely dark, and three times as bright as the background. In the case of curve *4*, the surroundings are just as bright as the background, but the test object has a size of about 4°. Data have been taken from Stiles and Crawford, Hoppe, and Siedentopf, Schumacher.

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[1]) The surfaces which occur in offices and living-rooms often exhibit approximately diffuse reflection. When this is not the case it is impossible to speak of one reflection coefficient, and in order to indicate the contrast direct use must be made of the ratio of brightness of detail and of background. The same is also true, of course, when detail and background do not receive the same illumination intensity.

object than the others; the contrast sensitivity in this case is higher over the whole range.

Similar behaviour as for visual acuity and contrast sensitivity is found for the speed of observation S_w, but here the increase with illumination intensity is only worthwhile up to 100 lux, above which it is only slight.

From all this information conclusions can now be drawn as to the improvement that can be obtained by an increase of the illumination intensity. Two objections must, however, be taken into account. The first is that this information naturally relates only to the threshold of observation. At a few lux already the angles of vision and contrasts occurring in the practical work to be performed lie in general far above this threshold [2]). The increase in the performance of the eye with increasing illumination intensity, as far as the threshold sensitivities are concerned, is thus of itself of no importance to us.

The other objection is that the visual acuity, the speed of observation and the contrast sensitivity are quantities of such a strongly conventionalized character that they cannot express the practical performance of the human eye.

An attempt to meet these two difficulties may be found in a recent investigation by Weston [3]). He used test objects presenting details of the size of 1 to 6 minutes and defined the performance of the eye with a given size of detail and contrast as the quotient of the relative number of correctly judged test objects and the time necessary for the observation of the detail. His conclusion is that for normal work (size of detail about 3′, corresponding to the reading of printed matter in Bodoni 10 points, see footnote [2])) the performance distinctly increases up to about 40 lux. At this intensity it already amounts to about 90% of that at 5000 lux. For fine work (size of detail 1′) there is a marked increase in the performance up to about 1000 lux, where again about 90% of that at 5000 lux is attained. These results constitute a further specification and a good confirmation of the conclusions to be drawn directly from figs. 1 and 2.

We now arrive at the last point in the list of characteristics of an activity, namely the duration. The effect of the duration manifests itself in the fatigue phenomena. It is remarkable that this fatigue is scarcely manifested in the performance of the eye as far as visual acuity and contrast sensitivity are concerned. The performance of an activity considered as a whole, however, is felt to be "more difficult". Parallel with certain physiological phenomena, such as more frequent blinking and a slowing up of the heartbeat [4]), a general decline in the performance of work is observed, a decrease in the rate of reading, in the accuracy of drawing, etc.

Fatigue tests.

The increase in the performance of the eye with increasing illumination intensity as discussed in the foregoing may be related to the more or less trivial fact that with increasing illumination intensity observation becomes "easier". From the shape of the curves of figs. 1 and 2 and especially from Weston's results it is possible, to some extent, to read off the degree of this increase in ease. The fact that an increase in illumination intensity makes observation "easier", while we have just ascertained that upon long duration of the activity observation of work becomes "more difficult", makes it reasonable to expect that illumination intensity will have an effect on the occurrence of fatigue. It is, however, obvious that it will not be so simple to determine this effect quantitatively as the effect on the observation thresholds, on account of the difficulty of expressing the effect of becoming fatigued in numbers.

Direct tests of fatigue have been made by Luckiesh and Moss [5]), among others. For a large number of test persons they investigated the fatigue occurring upon reading under accurately determined optical conditions which may be considered as an idealization of the conditions occurring in practice. They used various criteria of fatigue. The most obvious, *i.e.* the criterion which is most closely connected with the act of reading itself, is the decline in reading speed. Remarkably enough, however, this decline is always found to be only slight and consequently to exhibit only small differences for very divergent illumination intensities. According to Luckiesh and Moss [6]) this may be understood to mean that under worse visual conditions the eyes are stimulated by the brain to correspondingly greater effort. The relation between "fatigue" and speed of reading is thus lost for the greater part, so that speed of reading is not a very suitable criterion of fatigue.

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[2]) In reading printed matter, for example, the size of a normal letter type (such as Bodoni 10 points, which is used in the text of this article) is about 1·5 mm; the detail of each letter which makes it recognizable is usually about 5 times as small. At a distance of 30 cm from the eye the angle of vision is then 3·5. According to fig. 1 at 1 lux details down to about 1·2 can still be observed. Furthermore the reflection coefficient of the background lies between 0·8 and 0·6, that of the type between 0·04 and 0·10; the contrast thus amounts to from 1 : 6 to 1 : 20, while at 1 lux and 3·5 angle of vision contrasts of 1 : 2 can still be observed.

[3]) H. C. Weston, Industrial Health Research Report No. **87**, H. M. Stationery Office, London 1945.

[4]) M. Luckiesh and F. K. Moss, Trans. Ill Eng. Soc. **34**, 571, 1939.

[5]) M. Luckiesh and F. K. Moss, Trans. Ill Eng. Soc. **35**, 19, 1940; **35**, 703, 1940.

[6]) M. Luckiesh and F. K. Moss, Reading as a Visual Task, D. van Nostrand Co., New York 1942.

Another criterion used by Luckiesh and Moss in their tests is the frequency of the involuntary blinking during reading. This criterion is less directly connected with the act of reading than the speed of reading; but there appears to be a satisfactory correlation between greater difficulty in reading and more rapid blinking. Measurement of the number of blinks per unit of time at the beginning of reading and after 1 hour of reading gave the following results:

at 10 lux an increase after one hour of 72%,
at 100 lux an increase after one hour of 31%,
at 1000 lux an increase after one hour of 8%.

It is clear that under the higher illumination intensities less fatigue occurs; between 10 and 1000 lux a steady improvement can be observed with increasing intensity, although the improvement per lux increase in intensity rapidly becomes less at higher levels.

These results are quite parallel with our conclusions from figs. 1 and 2 about the increasing "ease" of observation, and we may therefore accept it as established that an increase in illumination intensity from about 10 lux to 100 lux is accompanied by a considerable improvement as far as fatigue is concerned, while an increase above 100 to 1000 lux is still accompanied by an appreciable improvement. Above 1000 lux no direct fatigue tests have been carried out, but on the basis of the parallelism already mentioned we may expect here also a slight improvement similar to the curves of figs. 1 and 2.

In the tests of Luckiesh and Moss use was made of very clearly legible printed matter. It may be expected that for less easily legible printed matter (smaller letters, little contrast with the background, as in carbon copies of typed material) more pronounced fatigue phenomena will be found. We may assume that in these cases the decrease in fatigue upon increase in illumination intensity will be at least just as great as was found in the tests with good printed matter. This conclusion also holds, of course, with respect to other activities which are more difficult than reading, for instance drawing, mending of clothing, etc.

In conclusion it must further be mentioned that in the tests of Luckiesh and Moss the influence of the brightness of the surroundings (at an illumination intensity of 135 lux) and of the spectral composition of the light was also studied. Equal brightness of surroundings and background were found to be most favourable. Incandescent lamps and luminescent lamps of daylight colour gave no appreciable difference in ease of reading.

Illumination in practice.

Let us now consider the practical application of the information obtained. The high levels of illumination found to be so favourable for the eye will seldom be found in offices and never in a living room. In the introduction we have already suggested the reason for this: it is the influence of a combination of other factors besides the behaviour of the eye. If we are to describe these influences in more detail we must consider offices and homes separately.

Offices.

For office illumination the utility factor is most important. Both for the initial installation and for possible alterations, it is primarily the economic advantages and disadvantages that are weighed.

What are the advantages? According to the foregoing an increase in illumination intensity will result in an increase in the production of the employees, which represents a certain money value. This increase will be considerable at low levels of illumination but will become less and less at higher levels, until finally there is no advantage at all. We thus obtain a variation of the advantages as indicated qualitatively by the continuous-line curve in *fig. 3* [7]). The region of illumination intensities where the curve is practically horizontal will lie higher according as the work performed in the office is more difficult.

Costs show an opposite trend. The additional expense entailed, for example, by doubling the illumination intensity is less at a low level of illumination than at a high level. The curvature of curve *1* in fig. 3, which shows qualitatively the variation of costs, is thus just the opposite of that of the continuous line curve representing the ensuing advantages. If the two curves are compared in two points pertaining to a given value of the illumination a certain value of the illumination intensity is found where the tangents are parallel. This is the point where the best economy is attained, because at a still higher illumination level the increase of expense is greater than that of advantages.

Due to advances in technique in the course of

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[7]) It is obvious that such a curve can in practice only be based on very rough estimations and often cannot even approximately be drawn. The general shape should, however, be like that indicated.

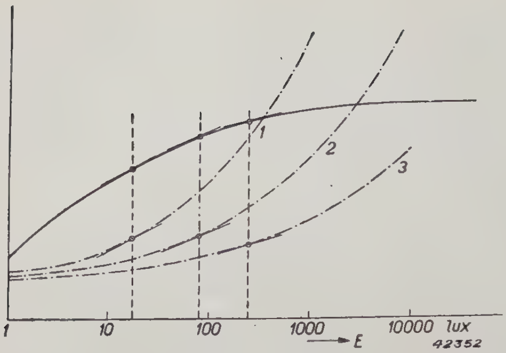

Fig. 3. Schematic variation of the advantages of an office illumination (full-line curve) and of the costs (broken-line curves) as a function of the illumination intensity. The three curves *1*, *2*, *3* correspond to increasingly higher stages of technical development. The most favourable illumination intensity lies at the value for E where the curves for advantages and disadvantages are parallel. With advancing technique this point shifts towards higher illumination levels.

time the curve of costs will fall with respect to the curve of advantages. The points showing parallel tangents will therefore be shifted toward the right, *i.e.* the most economical illumination level rises. Some indication of the height of that level at the present stage of technical development may be found in the values which are recommended by the lighting societies in various countries, see the *table* below [8]). The above-mentioned advance in technique is clearly manifested in the U.S.A. values for different periods.

Type of work	U.S.A.			Gt. Britain	Switzerland before 1940
	1930	1939	1942	1937	
Reading and writing with interruptions	80-100	200	250	100-150	150
Long-continued calculation or study	100-150	300-500	500	150-250	300

Since some time always elapses before practice adapts itself to technical progress, in most offices one encounters illumination levels which are lower than what are to be considered the most economical. As long as the level is not too low the difference is only a question of utility, as discussed above. It is, however, clear that at too low intensities phenomena must occur which can no longer be expressed purely in money value but which already belong to the sphere of hygiene. There will then be complaints by the employees of fatigue, headache, etc. General experience in the practice of factory and office lighting is that the limit above which these phenomena are no longer frequent for activities such as reading lies at about 100 lux.

This value is also found on the basis of the following considerations. The avoidance of complaints means that each individual worker must be satisfied with the illumination. The preceding discussion, however, referred to the average behaviour of a large number of persons. The effectiveness of vision for such a collection of persons, even though they are all "normal", will show a certain spread. The curve showing the spread of the contrast sensitivity and the visual acuity for a large number of persons has been determined (*cf.* for example the article referred to in footnote [4])). In both cases the curves deviate from the normal distribution curve of Gauss, but in the following we shall approximate them by normal distribution curves since that does not alter the order of magnitude of the results. In *fig. 4* curve *a* represents schematically the distribution curve, *i.e.* the number of persons N as a function of visual acuity, for an illumination intensity of 1000 lux. With each value of visual acuity, no matter what combination of conditions (which may be characteristics of the person or of the light) is responsible for it, we may correlate a definite value of the "ease of working". At what value of visual acuity is the ease of working unsatisfactory? From the fact that at 1000 lux practically none of all the test persons experiences any difficulty, we may conclude that the critical value of visual acuity will lie to the left of the point S in fig. 4. The part of the distribution curve a lying to the left of S contains fewer than 1% of all test persons. If we construct the corresponding distribution curve for a lower intensity than 1000 lux we obtain again, schematically, curve b, which is shifted to the left with respect to a. Now a larger percentage of all test persons falls below the limit S. The shift for an illumination intensity

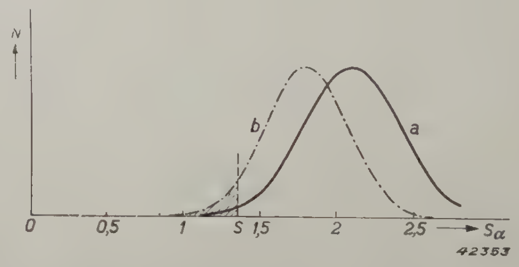

Fig. 4. Schematic representation of the spread of the visual acuity S_a of a large number of test persons. A Gauss distribution is assumed; the actual distribution deviates somewhat from that, but the deviation may be ignored for our purposes. Curve *a* refers to an illumination intensity of 1000 lux. At a lower illumination intensity the whole curve is displaced towards smaller values of S_a; thus for example at 100 lux curve *b* is found.

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[8]) It must not be forgotten that in establishing these illumination levels other considerations besides utility, such as, for example, that of the ease of the observation itself, have played a part. As to the values recommended in America, in the report in Trans. Ill Eng. Soc. **34**, 371, 1939, the preliminary studies for the recommendations of 1939 are included. These preliminary studies contain a discussion of economic advantages and disadvantages; the conclusion is that the increase in the advantages at the levels given more than balances the increase in expense. The most recent American recommendations are to be found in Trans. Ill Eng. Soc. **37**, 275 and 449, 1942; **40**, 339, 1942. A new proposal for Gt. Britain is in preparation; Trans. Ill. Eng. Soc. (London), **8**, 17, 1943.

of 100 lux, however, according to the experiments is found to be still so small (about 40% of the distance between S and the maximum of curve a) that again the total percentage of persons whose vision lies below S is still small, namely 5%. Analogous arguments hold for the contrast sensitivity, the same qualitative conclusion being reached: at 100 lux 3% of the persons fall below the limit S. The probability that a person possessing "normal" vision will encounter difficulty from too little light is therefore also small at 100 lux. With less than 100 lux, however, this probability increases rapidly.

Similar considerations can be found in the article by Weston[3]) already referred to. At high illumination intensities the performance values found for different persons show only a small spread. At lower illumination intensities the relative spread increases, this being ascribed to the fact that the conditions of seeing become too unfavourable for some persons. The limit depends upon the kind of work, but always lies at about the illumination intensity at which the "performance" reaches 90% of the maximum value, thus, according to the values given above, at 40 lux for ordinary work and at 100 lux for fine work.

The living-room

In the case of the illumination of the living-room the situation is quite different from that of the illumination of offices, because the living-room is used not only for certain activities such as reading, mending, etc. but is alternatively also the cosy gathering place of the family, the festively lighted reception room or the quiet surroundings where rest is enjoyed. In order to obtain suitable light distribution in all these cases, different illuminations will have to be installed which can be used separately or in combination.

We shall confine ourselves here to a consideration of the illumination which will be employed when the living-room is used as a work room. From the discussion of office lighting it followed that for activities such as long-continued reading, intensities of at least 100 lux must be employed. This result was not reached on the basis of considerations of utility — which are of less importance in the case of the home — but on the basis of considerations of hygiene. The minimum limit can therefore also be considered valid for the living-room. Having regard to the poorer vision of older persons and the greater difficulty of some types of household tasks, embroidery for instance, as compared with reading, it is better to choose a 50 or 100% higher illumination intensity.

What is now the situation as regards the realization of these illumination levels in the living-room? The solutions arrived at for the office would not in general be acceptable in the living-room, since, even though it is used as a work room, a domestic sphere is desired which cannot be combined with the technical austerity of utility illumination. Esthetic considerations here occupy the foreground: the lighting ornament must harmonize with the interior, and that not only when lighted but also in the daytime. The shape and colour which it exhibits in the daytime are indeed usually the criteria which decide the choice of a given ornament, while the illuminating technical characteristics are usually given too little consideration. The illumination intensity is often quite insufficient, even when using the largest lamp permissible in connection with the heat development, to say nothing of the distribution of the light flux and the precautions against glare.

It is no wonder that in almost all living-rooms illumination intensities are found which lie far below what is desirable in a work room. If the eye protests too strongly recourse is usually had to extra local illumination, which, however, when several persons are working at the same time cannot be considered a satisfactory solution.

Having pointed out this rather disappointing state of affairs, we need not resign ourselves to it. At the present day it is without doubt technically possible to install an esthetically satisfactory living-room illumination of sufficiently high level, and in this respect two points have been found to be of great importance.

1) The esthetic acceptability of an illumination depends very much on the relation between the brightnesses of the surfaces occurring in the room (table cover, ceiling, walls). With a very light table covering the surroundings should also be light, since it is found that with increasing brightness large contrasts make a more and more unpleasant impression. Dark walls already form of themselves a great contrast with the working surface; from economical considerations they also hinder the employment of indirect lighting, which is so useful for reducing contrasts, and thus quickly set a limit to the illumination intensity. In interiors with light walls and not too dark upholstering, illumination intensities of 150 to 200 lux are much more easily attainable than in darker surroundings. The correct technical construction of the fixture to distribute the light in the desired manner over the working surface and surroundings no longer presents any problems with the present-day technical development.

2) The level of the illumination considered as being "cosy" or "pleasant" is related to the colour of the light. For the above-mentioned illumination intensities of 150 to 200 lux no unplea-

sant effects [9]) are, it is true, experienced with the reddish light of incandescent lamps, but a whiter light, more nearly approaching daylight, may in some cases give the whole interior a more agreeable aspect. The possibility of such an improvement in colour is now offered by the development of luminescent lamps [10]). At the same time, with the smaller heat development of these lamps there are no difficulties with the fixtures in that respect.

It may be hoped that these new possibilities will ultimately remove the great difference between the desirable and the actual illumination intensity in the living-room when it is used as a work room.

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[9]) See Philips Techn. Rev. **6**, 69, 1941.

[10]) Philips Techn. Rev. **6**, 65, 1941.

MAINTENANCE MEASUREMENTS ON CARRIER TELEPHONY EQUIPMENT [a]

by J. de JONG.

621.395.44:621.317.3

The maintenance of telephony equipment involves many complex and very accurate measurements, the most important of which are measurements of level, for ascertaining the strength of a signal at different points in a line of communication. The equipment employed for this purpose, as well as for other measurements, is described in the following, which deals in particular with the influence of the special requirements appertaining to telephony, upon the construction of the equipment and the manner in which these tests are carried out. For example, accuracy and stability of the test gear are of the utmost importance: again, it must be possible to perform the tests while the system is in operation and, moreover, at many different points in the equipment, possibly even some hundreds of miles apart. In view of the comprehensive nature of the tests, the apparatus must be at once adaptable to any special contingency (impedance, levels, earthing etc), while all the necessary adjustments and readings must be quickly and readily accomplished.

Few branches of technology necessitate such far-reaching test-schedules, or place such high demands on accuracy of measurement as Telephony, and this applies not only to the development of new equipment and components, but equally to the many special tests carried out in the manufacture and installation of this type of equipment. We are more especially concerned, however, with what may be called maintenance measurements, by which is meant those measurements essential to the proper upkeep of the equipment and the communications which it maintains. The importance of such measurements will be manifest when it is recalled that every channel of communication involves the use of the most complex types of equipment, whilst, secondly, the risk of interruption in the service must be minimized as much as possible.

Maintenance measurements may be divided roughly into two categories, the location of faults and purely preventive inspection. The object of the first is to detect and localise sudden causes of failure, but by far the greater part of these maintenance tests is of a preventive character, since constant checks on the performance of the equipment will reveal latent causes of breakdown, for instance ageing of valves, variations in cable-losses due to fluctuations in temperature etc., all of which may be detected and remedied before an actual failure occurs. Such preventive measures are of particular importance in carrier communication, for which far more elaborate equipment is necessary than in the case of low-frequency telephony. Not only are the chances of faults therefore much greater, but any single fault may lead to an interruption of various channels of communication. In the case of the earlier system developed by Philips, employing 17 speech-channels, the failure of one of the repeaters results in the interruption of all 17 calls carried by any single pair of conductors in the cable. All the channels, including those of other pairs, are interrupted if the carrier supply common to these pairs becomes defective.

The introduction of carrier telephony has brought with it a great increase in the extent and nature of the tests to be carried out; for example in the 17-channel system alluded to the frequency range to be covered by the measurements has been increased from about 3000 to roughly 100 000 c/s, whilst, apart from cross-talk between the different pairs, it is now also necessary to measure the mutual effects among the 17 channels of any single pair.

Of those maintenance measurements which are of special importance in the upkeep of carrier-telephony communication we now propose to discuss the following:

1) Measurements of level, including the current strengths and levels of speech of signals at various points in the channels. (The level is defined as the ratio of the strength at any given point to that at the origin of the connection, converted to the same impedance.)
2) Cross-talk measurements between the various channels.
3) Checking of the working of the amplifier valves.
4) Location and identification of interfering frequencies and measurement of distortion.

The very extensive measurements of level will be dealt with in some detail; the other points will be examined more briefly. Further tests, such as

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a) Editor's note. This article is the last of a series on carrier telephony commenced in 1941 and based on the 17-channel system. It is hoped that shortly a description will be forthcoming of a new carrier system developed in recent years.

those applied to signal and selector equipment, the inspection of telephone cables, subscribers, instruments and connections, will not be touched upon.

Measurement of level

In the construction of present-day telephone networks it is stipulated that attenuation of speech between one subscriber and another, within the boundaries of the country, shall not exceed 28.5 db, as this ensures reasonably intelligible conversation. Of this tolerance, twice 6.3 db is reserved to cover the relatively short connections between subscriber and exchange and this margin is sufficiently wide to dispense with regular tests which would otherwise be far too costly. On the other hand, the total losses in trunk connections that may be some hundreds of miles apart might easily exceed the remaining maximum of 15.9 db, due to temperature variations and so on. Again, such variations may even produce "negative losses" to such an extent as to cause instability (manifested by a howl in the telephone at each end of the line, so shrill as to drown ordinary speech and render conversation quite impossible).

In this form of communication, in which the working pressure is so great, the costs may be correspondingly higher and a continuous check on the losses must therefore be maintained.

This means that at the terminal station and at each of the repeater stations — of which there may be 10, 20 or even more on a long distance run — the levels of the incoming and outgoing signals have to be measured regularly and amplification readjusted to maintain the levels within the prescribed limits. These tests need to be carried out at several frequencies individually and the losses, which differ to a lesser or greater degree between one frequency and another, are subsequently equalised by means of small correction networks. The measurements necessitate the use of a test-oscillator capable of supplying an alternating voltage of variable frequency (within the whole range of speech frequencies to be transmitted), that is, in ordinary low frequency telephony, roughly from 300 to 3400 c/s. This oscillator is connected to the input end of the connection under test and an A.C. voltmeter is applied to the output end to measure the strength of the signals received.

Measurements in connection with carrier telephony are of a more complex type, the frequency range being much wider; in the case of the 17-channel system the appropriate oscillator and measuring instrument need to be suitable for the frequencies already mentioned, namely up to about 100 000 c/s. Another complication arises from the transformation which the speech frequencies undergo and in this connection reference is made to the diagram of a carrier channel depicted in *fig. 1.*

A speech frequency q is impressed by the modulator upon a carrier wave of frequency p. This furnishes two side-band frequencies $p \pm q$, as well as others, such as $2p$, $3p \pm q$ and so on, and that side-band whose frequency is $p + q$ is employed for transmission, the others being suppressed by the

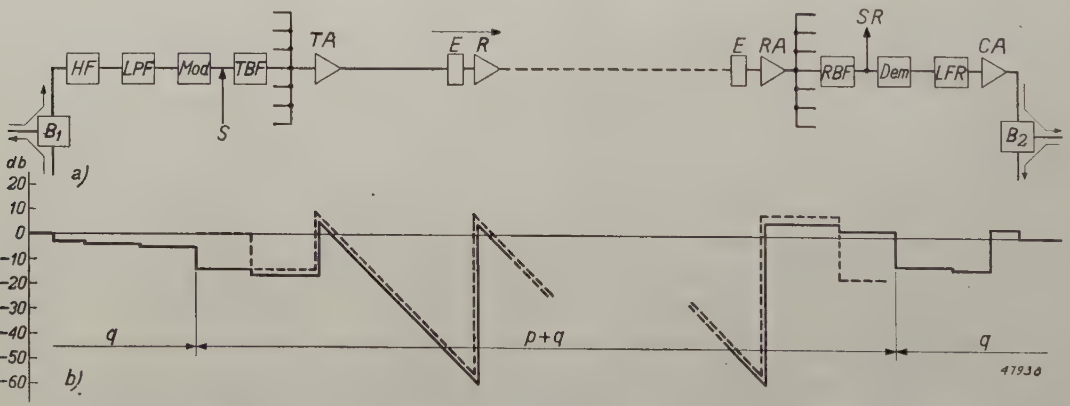

Fig. 1. *a)* Diagram of a carrier channel for telephony. B_1 = branch; *HF* = high-pass filter; *LPF* = low-pass filter; *Mod* = modulator; *TBF* = transmission band filter; *TA* = transmitter amplifier; *E* = equaliser; *R* = repeater; *RA* = receiver amplifier; *RBF* = receiving band filter; *Dem* = demodulator; *LFR* = low-pass receiving filter; *CA* = channel amplifier; B_2 = branch. Further, for carrier signalling: *S* = carrier wave injection; *SR* = connection for signal receiver.

b) The relative level diagram in respect of all the components under normal working conditions. The full lines show the level of speech at the various points in the system illustrated in the upper figure. It is assumed that the output and input levels are exactly equalised. At a speech frequency q and carrier frequency p, the signal under test will have the frequencies as shown. The broken line refers to the carrier used for signalling purposes.

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1) See Philips Techn. Rev. 7, 83, 1942.

transmission-band filter. Now, if it is desired to check the losses in the modulator, a frequency q is applied to the input and the voltage of $p + q$ is measured at the output. To ensure the exclusion of other frequencies at this point, a very selective measuring instrument, known as an analyser, is employed, this being also used for measurements of level following the transmitting band filter, for example, somewhere in the cable. It is true that it would be quite possible to apply only frequency $p + q$ by means of the oscillator, to the input of the transmitting band filter, but it must be remembered that at the other end of the band filter we are also concerned with the frequencies of all the other channels on the same pair of conductors.

In telephone work, in general, it is usually laid down that it must be possible for tests to be carried out on any one channel while the others are in normal operation, and the analyser is therefore essential for the elimination of the frequencies of the other channels.

When levels are measured in this way at the input and output sides of all the components of a given channel, a diagram is obtained of the kind depicted in fig. 1*b*. The level of the carrier transmitted for signalling [2]) is also shown, in broken lines.

The losses in the transmitting band filter with respect to the carrier frequency tend to vary very considerably with the temperature, seeing that this frequency is located just at the edge of the pass band; therefore, measurement of the level and subsequent correction are of particular importance.

Speaking generally, these remarks also apply to the highest frequency channels, since the absolute width of the frequency range is actually the same in all the channels (3 100 c/s, corresponding to speech frequencies of 300—3 400 c/s); the relative bandwidth in the highest channels is therefore much smaller than in the lower, so the effect of temperature variations in the coils and condensers upon the losses of the bandfilters, at the edges of the ranges passed by them, is greater in the higher than in the lower channels.

Description of the equipment required

The equipment by means of which the measurement of level is carried out will now be considered in greater detail, and our description is based on the types of instrument that would be suitable for the maintenance of the 17-channel system to which reference has already been made.

The Oscillator

The oscillator is constructed along the same lines as the audio-frequency instrument described in a previous issue of this Review [3]), the required frequency in this case being the heterodyne of two alternating voltages of higher frequency, generated by two oscillator valves. In order to provide beat frequencies up to 100 000 c/s, the frequency of one of the oscillators is designed to give 400 000 c/s, whilst that of the other is variable between 400 000 and 300 000 c/s. The beat frequency is filtered out and amplified to the desired level, which, to meet the required accuracy of measurement, must be the same over the whole frequency range, to within 0.1 db. Since it is not an easy matter to construct an output transformer, such as is needed for matching purposes, that will give a sufficiently straight characteristic over the entire frequency range of 30 to 100 000 c/s, two output transformers are provided for switching in as required. One of these is employed for the frequencies from 30 to 10 000 c/s and the other from 4000 to 100 000 c/s. The transmitting level is adjusted to the required value by means of a calibrated attenuator.

Fig. 2 illustrates the arrangement of the oscillator.

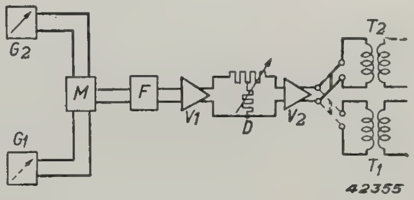

Fig. 2. Simplified diagram of the oscillator. G_1 = fixed frequency oscillator; G_2 = variable frequency oscillator (the frequency of G_1 can also be varied to a certain extent for trimming purposes); M = mixer stage; F = filter for suppressing all voltages of which the frequency is over 100 000 c/s; V_1, V_2 = amplifiers; D = calibrated variable attenuator; T_1, T_2 = output transformers.

The oscillator has to meet very stringent requirements from the aspect of "reproducibility" of the frequency setting, in connection with the previously mentioned frequency drift to which the speech frequencies in carrier telephony are subject. The absolute error in the test frequency in the higher channels (72 kc/s) must not be greater than in the lower, *i.e.*, a maximum of about 20 c/s, which means that the higher oscillator frequencies must be capable of adjustment and indication within an accuracy of 0.03% and that, despite variations in temperature etc. during testing, they must not drift more than a fraction of this 0.03%. Due attention to the temperature coefficients and careful disposition of the components in the chassis, with respect to sources of heat, such as the valves and power pack, have made it possible to satisfy these requirements.

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[2]) See Philips Techn. Rev. **8**, 168, 1946.

[3]) "A Tone Generator" by L. Blok, Philips Techn. Rev. **5**, 276, 1940. The instrument described therein is not required to meet such stringent requirements as those arising in telephony.

The maximum output is 850 mW, but the sizes of the components, especially the amplifier valves, are very much more generous than would be normally expected for such a relatively low output power, and the reason for this is to be found in the special demands made upon them; in telephony all the valves, including those in the measuring equipment, are almost continuously in operation, so that a much longer guaranteed life is necessary than for the average radio valve, which is in use only for a few hours each day. For this reason the valves in the oscillator are of a relatively larger type.

The level-meter

This unit (*fig. 3*) comprises in the main an amplifier suitable for frequencies of 30-100 000 c/s and a double-diode rectifier, followed by a milliammeter of which the scale corresponds to a range of 14 db, giving easy reading to within an accuracy of 0.1 db. In practice the levels actually differ by much more than 14 db, for, in the diagram of levels *fig. 1*, one channel alone reveals differences of from 5 db above to 60 db below the so-called zero level (1 mW).

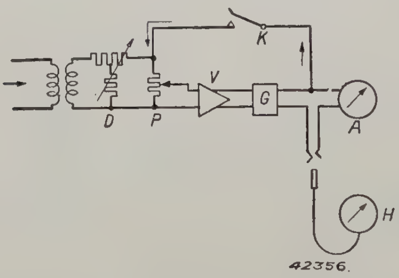

Fig. 3. Diagram of the level-meter. D = calibrated attenuator; P = potentiometer; V = amplifier; G = rectifier; A = meter; H = auxiliary, plug-in hand meter, for use if required. When switch K is closed the feed-back produces oscillation, for use in "internal calibration".

In some instances the line repeaters provide amplification to the extent of 65-70 db and the level-meter is therefore also provided with a calibrated, variable attenuator for reduction of the sensitivity of the unit to the required value. The weakest signals to be measured lie 72 db below the zero level (potentials of about 30 μV) and the strongest are 30 db above it (potentials of 70 V); the attenuator is very carefully designed to avoid the possibility that unusually high input voltages might in themselves affect the output and disturb the reading of the instrument. With the same object in view, care is also taken with the wiring, whilst due consideration is given to the reduction of stray impedances, in order to ensure the required flat characteristic over the whole of the very wide frequency range of 30 to 100 000 c/s.

The dial calibration of the milliammeter is correct only in respect of a certain definite degree of amplification from the built-in amplifier, and this setting can be readily checked by means of the feed-back which causes the amplifier to oscillate. The deflection of the meter is governed by the degree of amplification, which is made to correspond to the calibration line on the dial; should the setting be incorrect, the amplification is adjusted by means of the potentiometer P in fig. 3 (internal calibration).

The Analyser

This instrument must be capable of filtering from a composite signal a very carefully determined and readable frequency and of measuring the strength of this frequency. A filter is used that will pass only a very narrow band of frequencies in the region of 370 c/s and the signal under test is converted to 370 c/s by modulation with a carrier wave of variable frequency, see *fig. 4*. The circuit may therefore be regarded as the reception channel of a carrier system in which the carrier wave employed for modulation is variable and of which the channel amplifier admits only one frequency, of 370 c/s, this having been chosen to avoid confusion with possible harmonics of the main frequency.

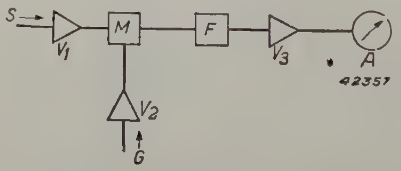

Fig. 4. Diagram of the analyser. S = input for signal under test, of unknown frequency f; G = input for an indicated frequency, variable within 1 or 2 c/s; M = modulator; F = sharp cut-off filter for 370 c/s; V_1, V_2, V_3 = amplifiers. A = measuring instrument to deflect only when G supplies a frequency of $f + 370$ or $f - 370$ c/s.

The fact that an analyser of this type is definitely essential for the measurement of high values of filter-loss can best be illustrated by means of an example. Suppose it is required to measure at 2000 c/s a high-pass filter of which the cut-off frequency is 3000 c/s, using an oscillator of which the inherent distortion is 0.1%, *i.e.*, the sum of all the harmonics is 60 db below the fundamental. Now, if a straight-characteristic test-amplifier were used instead of the analyser, it would not be possible to measure a greater quantity of loss than 60 db, seeing that all harmonics of 2000 c/s would pass the filter without any attenuation and produce a signal just as strong as the 60 db damped fundamental frequency. The analyser, on the other hand, first eliminates all harmonics and heavy background noises, after which only the strength of the fundamental frequency of 2000 c/s is measured, this being passed by the filter and exactly reproducing the filter losses at that frequency.

Construction of the equipment

For the daily testing of a large station, the necessary measuring equipment is mounted on a special panel as depicted in *fig*. 5; this is located at a central point in the station and is connected by permanent wiring to all the panels at which regular measurements of level are taken. On each of the latter panels, for instance that of the channel amplifier for the 17-channel system, a jack *A* is provided, connected to the output voltage of the oscillator and a similar jack *B*, connected to the input of the level-indicator. Further, the inputs and outputs of the components on that panel (in this case the channel amplifiers) are all taken to a jack-panel, so that, using only two leads with plugs at the points *A* and *B*, it is possible to check all the components in quick succession.

Measurements are carried out by two inspectors, one of whom makes the necessary adjustments to and takes readings from the test panel, while the other completes the successive connections to the different components at the panel to be tested. The inspector at the latter can also take readings, if desired, by means of a hand meter connected in series with the instrument on the test panel. This is convenient if any adjustments to the panels are to be made, *e.g.* matching of modulators 4) or readjustment of the amplifiers.

The great rapidity of measurement made possible by this division of labour is of the utmost importance in view of the very numerous measurements that have to be made regularly, especially in the larger stations, where sometimes 10 or 20 carrier systems are mounted side by side.

In smaller stations no test equipment is normally available and this has to be brought to the spot as and when required. It is understood in all measurement work that a call taking place over the channel under measurement shall not be interrupted and, during the time taken for such measurement, the calls are transferred to special spare channels.

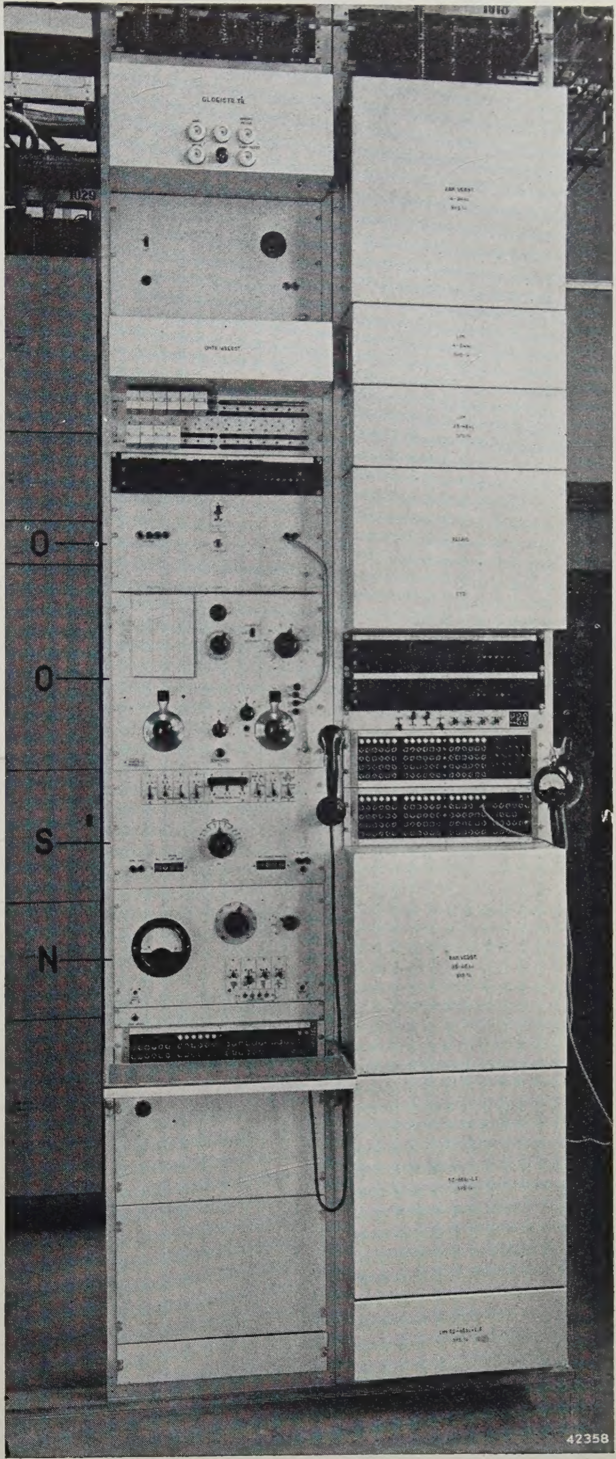

Fig. 5. The test panels, as mounted in a Philips 17-channel carrier station. O = oscillator; N = level indicator; S = switch panel. The right-hand panel contains the channel amplifiers and the illustration shows the jack-panel to which the input and output jacks of all the amplifiers, as well as tappings from the anode circuits, are grouped. On the right-hand side, by the jack-panel, there is a hand-meter for checking the amplifier valves.

Fig. 6 shows a photograph of the analyser, designed as a readily transportable instrument for

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4) Philip v. Res Techn. 7, 83. 1942,

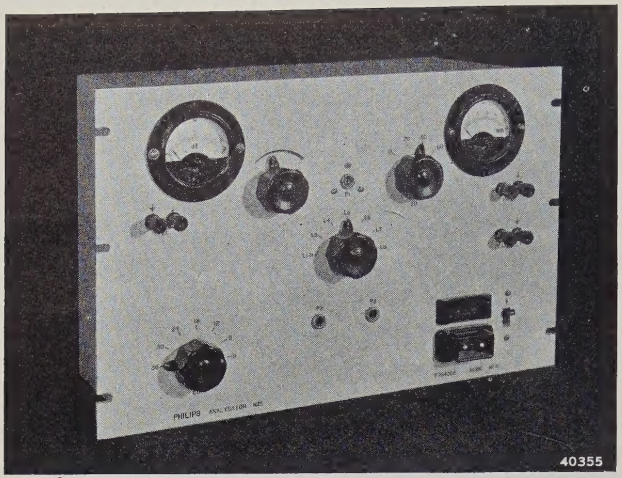

Fig. 6. The Analyser. One of the meters is for checking the symmetrical setting of the balanced modulator, whilst the other indicates in db the strength of the signal to be tested, a calibrated attenuator being provided for this purpose.

mounting in a panel or wooden box, the latter being preferable for locating faults, as it can be connected to any desired point in the system or used for measurements in unattended terminal or repeater stations. The oscillator and level-indicator described above can be similarly built into standard wooden boxes and the latter, mounted in this manner, is shown in *fig. 7*.

Ancillary apparatus used in normal operation

For the transmission of speech over telephony channels embodying a large number of elements (four-wire circuits) it is essential that losses due to reflection in these circuits be reduced to the greatest possible extent, which means, in effect, that each four-wire circuit must be terminated by its so-called characteristic impedance and, to simplify matters, a certain amount of standardisation has been introduced. In low frequency telephony equipment (up to 10 000 c/s) each of the elements in the connection must have an impedance of 600 Ohms, or, in the case of higher frequencies (up to 200 kc/s), 150 Ohms. Then, in order to determine the impedance of any one component this must be similarly terminated, exactly as under working conditions. If the oscillator *0* (*fig. 5*) is substituted for the preceding components and the level-indicator *N* for the subsequent elements, the output impedance of the oscillator and the input impedance of the level indicator must conform to the prescribed value of 600 or 150 Ohms. Again, it may be desired to measure the level of a line whilst in normal operation: the level indicator, or, if required, the analyser is then connected in parallel with that line, in which event the introduction of the meter into the circuit must not produce any alteration in the speech circuit, *i.e.* the level must not be changed more than 0.1 db. The input impedance of the level indicator is then set to a very high value, *i.e.* 30 000 Ohms for a line of 600 Ohms.

The switch panel *S* shown in *fig. 5* incorporates the necessary equipment for the adjustment of the oscillator output and level indicator input, as required, to the impedance values mentioned (which must be constant throughout the whole frequency range of 30 to 100 000 c/s) [5]).

Further, by means of a calibrated attenuator it is possible to reduce by 60 db the transmitting level, normally of 1 mW, but which for purposes of checking the performance of the limiters and certain other components may be 6 mW. This facility is desirable notwithstanding the availability of the calibrated attenuator in the oscillator itself, since in some instances the carrier feed-voltage of the whole unit is employed as test signal instead of the

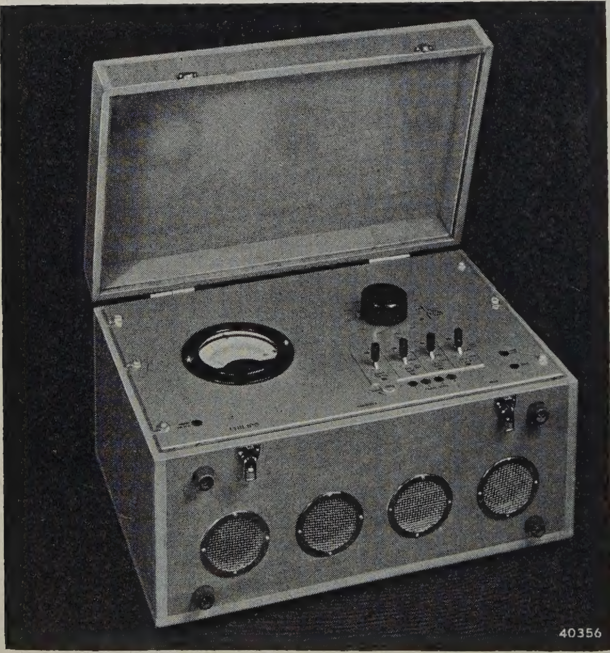

Fig. 7. Level indicator, mounted in a robust wooden box. The construction, as indeed that of all the equipment described, must be extremely rigid to avoid distortion of the chassis, buckling of the front panel etc. and thus exclude any possibility of consequent changes in the electrical properties.

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[5]) The impedance of 4-wire circuits is seldom exactly 600 or 150 Ohms over the whole frequency range, due amongst other things to the presence of unavoidable capacities and inductances. It is only in certain parts of the range, *e.g.* in the case of the bandfilters, in the centre of the channel that the impedance exactly meets the required value. Nevertheless, the measurements are carried out with impedances of 600 or 150 Ohms, as these not only always furnish comparable results but the arrangement also approximates working conditions, in so far as attenuators for balancing or adjustment are often used, of which the impedance is actually quite independent of frequency.

oscillator voltage, and the 17 jacks seen on the small panel in the lower part of the equipment (fig. 5) serve this purpose.

The transmitting and receiving cables forming the connections between the switch panel and the various other panels will in some cases carry signals of widely different levels, and checking of the amplifiers may reveal differences of as much as 70 db; in order, therefore, to ensure the required accuracy of measurement, the transmitting and receiving cables must be very carefully screened from each other. The method of earthing the screening, too, is of great importance. According to whether the input or output of a component to be tested is balanced or not with respect to earth, the screening, which is provided in each case with separate leads, is connected to different earthing points: the jacks referred to above are then so arranged that when the plugs are inserted the screens on the relative wiring are automatically inter-connected.

All the adjustments described in the foregoing, such as the impedance of input or output, the transmitting level, or earthing, are accomplished by means of a group of switches on the switch-panel; the use of keys or special tumbler switches, to permit of rapid action and to provide a simple means of reversing numerous contacts simultaneously, is a typical feature of telephone equipment construction. In the design of these keys, however, due consideration must be given to the fact that at higher frequencies, in the region of, say, 100 000 c/s, they may tend to form a shunt across the 150 Ohm line-impedance and upset the matching.

In conclusion, it should be noted that the two inspectors, working together on the measurements in the manner described, may well be some hundreds of miles apart, for example when measuring the losses in the cables or inter-station connections. To meet such contingencies, the switch panel includes the necessary connections to permit of the transmission of instructions and reports telephonically over the actual line under test.

Other measurements

A few additional maintenance tests mentioned in the opening paragraphs will now be briefly discussed.

Cross-talk measurements

Measurements of cross-talk are virtually measurements of level, with this difference that the signal is applied to the input of one speech channel, whilst the level of the resultant interference is measured at the output end of another channel. For this purpose it is necessary to select different frequencies according to the degree of annoyance caused to the listener, and this process of selection is made possible by a filter possessing a very definite characteristic; the equipment incorporating an instrument of this type is known as a psophometer [6]).

In general, cross-talk measurements only become necessary in the event of an actual defect, such as damage to a cable, which would disturb the balance between the pairs of conductors. In these cases the

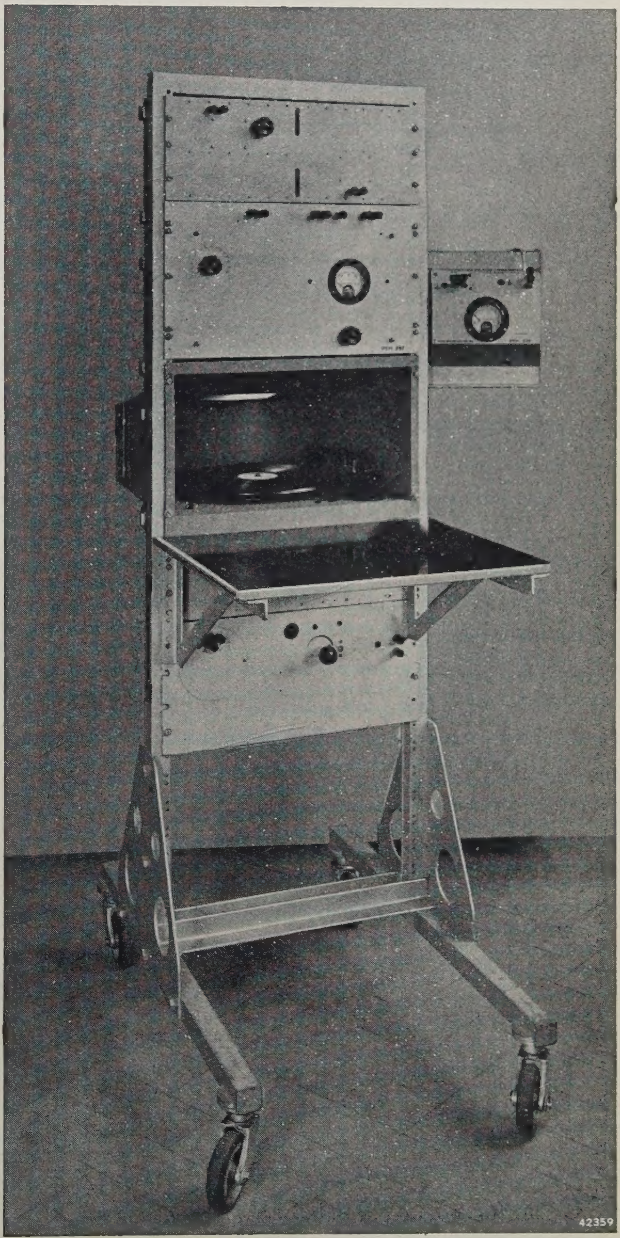

Fig. 8. Transportable equipment for cross-talk measurement. Top: the psophometer [6]); below: the play-back apparatus for the speech records. On the right: the volume-meter.

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[6]) See Philips Techn. Rev. 7, 108, 1942.

number of measurements to be taken is extremely large, 552 individual measurements being necessary for the checking of mutual cross-talk between 24 pairs of conductors in a carrier cable.

Fig. 8 depicts the equipment used for this kind of measurement. The outgoing signal usually consists of speech, and to provide speech of a readily reproducible character and level specially selected gramophone records are employed, of which the play-back strength is controlled by means of a specially adapted volt (volume) meter. The play-back unit and psophometer are mounted in a transportable panel, to enable cross-talk measurements to be made for the purpose of localising faults at various points in the system.

Measurements of the strength of hum and background noises are also carried out with this instrument.

Checking the amplifier valves

In a terminal station serving a number of carrier telephony lines many hundreds of amplifier valves are used, each of which in the course of time deteriorates and requires replacement before an actual interruption in the line occurs. These valves, then, are inspected at regular intervals, for instance once per week, and it is sufficient in the case of most of the valve types to measure the anode current under normal working conditions. So that this may be done rapidly, two tappings are taken from the anode resistance of each valve to a jack and all the jacks associated with each panel of valves are grouped on the common board to which reference has already been made. The different anode currents are read direct from a portable milliammeter, plugged successively into the appropriate jacks. For varying types of valve the anode tappings in question have to be arranged differently, in such a manner that the full deflection of the meter can be used in each case, and this would normally mean a special scale for each different type of valve. Since the Philips Carrier Equipment under review employs only two distinct types, however, it is only necessary for the meter to be fitted with two scales. To facilitate reading these scales are printed in different colours and each jack is marked with its appropriate colour.

The anode current of some types of valve does not necessarily furnish adequate evidence of its proper working, a more important feature being the slope, and this is obtained by measuring the anode current at two different values of grid bias. The jacks relating to such valves are therefore provided with a key, by means of which the bias can be set to a value other than the normal and this second measurement can be taken.

Interfering frequencies; distortion measurements

As we have already shown, the modulators in a carrier system not only supply the desired sidebands but numerous other, undesired frequencies as well, and in certain circumstances the latter may tend to pass into the particular channel or even into other channels, causing troublesome whistles. The highest degree of accuracy is often needed to identify such frequencies and trace them to their source, and this work can be very conveniently carried out by means of the analyser described in the preceding paragraphs.

The same instrument is also used for the measurement of non-linear distortion; a particular frequency is applied to the suspected component and the strength of the resultant second and third harmonics etc. is then measured. Special equipment can, of course, be constructed for the direct measurement of distortion, but as these tests lie virtually on the border line of normal maintenance measurements in carrier telephony it has not been found necessary to develop such special instruments for the particular system mentioned above.